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PRACTICAL PHYSICS

(For First Year T. D. C. Students)

By

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INTRODUCTION

The keen desire for experimentation and keen sense of observation lead a student of science to learn things thoroughly and sometimes to reveal the secrets of nature. A student of physics is required to be more skilled in performing experiments and more analytical in interpreting his results. Inside the laboratory a student is required to be perfectly disciplined to have the maximum advantage of the facilities available to him.

Laboratory is the sacred place of learning and it contains things which are our national property meant to be used by students in their turn. One should know about the use of every piece of apparatus before he handles it otherwise there is every possibility of spoiling or damaging it and such losses we are ordinarily unable to afford.

In the present pattern of science education in our country where number of students are increasing and the laboratory facilities are limited; a student is required to make the best use of the opportunities available to him. Inside the laboratory one is required to have the keen sense of fellow feeling amongst his class-fellows, obedient to his instructors and generous to lab-bearers. To have the full benefit of his laboratory opportunity, he is required to organise his working as follows:-

(a) Preparation outside the laboratory.

(b) Performance of an experiment.

(c) Recording.

Preparation outside the laboratory—As a practice, generally, students are given a laboratory programme in advance at the beginning of every academic session which has to be followed rigidly by every student in order to complete his practical work usefully in time. Of course, sometimes, it becomes inevitable to re-adjust it due to certain unavoidable reasons and students are required to take the due notice of such changes in their own interest.

As every student is aware of the fact that he has to perform a certain experiment on fixed date. He is, therefore, required to

prepare for the experiment before hand. It is v
that a student should be very inquisitive to under
of performing a certain *experiment. This in*
naturally, lead him to think about the experim
ment of his inquisitiveness he will read the r
principles. Its practical realization will make l
apparatus required and its particular use. He sh
keen to know the limitations of his apparatus and
ment can be affected.

To prepare for an experiment every *studen*
have an extra exercise-book, in which he should
formula to be used, explaining the symbols after un
relevant theory. A neat diagram and observatio
also be already made by him. If he has got some
must clear them with the help of his teacher. To e
proper preparation the teacher should put some ba
the students. This practice decisively, will give bett

Performance of an experiment—As soon as a
mitted to perform a certain experiment in the labora
collect all necessary apparatus for that experimen
them in a planned manner. After ascertaining that
the apparatus is in the working order, one should im
ceed to perform the experiment and take all the obser
pre drawn tabular form. He should take as many ol
he can take conveniently during the alloted time.
piece of apparatus is found to be not in the working
tain discrepancy is observed in the different sets of
the matter should be brought to the notice of the teac

If any apparatus is damaged or lost by a studen
also be immediately reported to the teacher concerne
can be replaced by the other apparatus. *If certain mist*
zed in the observations taken, then they should be
drawing a line over them and fresh readings *should be*

After *completing the experiment*, calculation sho
finished in the laboratory itself and the result obtained
communicated to the teacher. *On* his approval the
should be recorded in the well bound practical book.

For calculation purposes, one should know how to use trigonometrical tables, log tables, square and square root tables, reciprocal tables etc.

Sometimes the result is better interpreted in terms of graphs, therefore, plotting of graph and its interpretation should also be studied by students.

Recording—A well bound practical book is used for this purpose where right hand pages are ruled and left hand pages are plain.

The experiments whose results have been approved by the teacher should be recorded in the practical book as far as possible before performing the next experiment. The method of recording is given with each experiment described in the book but a general method is pointed out below in brief.

Experiment No.	(On the top of the ruled page)
Date	In the left hand column of the right hand side ruled page.
Object	Right side
Apparatus	Right side
Diagram or figure	Plain paper on the left side
Theory	Right side
Procedure	Right side
Observations	Right side
Calculations	Left side in neat manner
Result or interpretation	Right side
Percentage error	Right side
Precautions	Right side
Sources of error	Right side

After recording an experiment it should be produced before the teacher for examination before the next assigned experiment is started.

Use of mathematical tables—Use of mathematical tables except the log tables is simple and one can pick up their use just being properly instructed. The use of log tables need some understanding and we discuss their use in short.

The expression

$$a^n = b$$

mathematically can be written as

$$\log_a b = n$$

It is read—log of b to the base a is equal to n. For example

$$10^2 = 100$$
$$10^3 = 1000$$

can be expressed as logarithms as follows

$$\log_{10} 100 = 2$$
$$\log_{10} 1000 = 3$$

Generally for the purposes of calculations we use the log with base 10 and four figure tables. Log tables are useful to perform multiplication, division, evolution and involution. The basic rules of these operations with the logarithmic system are—

If $x = abc$

Then $\log x = \log abc$
$= \log a + \log b + \log c$ ......(1)

If $y = \frac{c}{d}$

Then $\log y = \log \frac{c}{d}$
$= \log c - \log d$ ......(2)

If $x = a^n$

Then $\log x = \log a^n$
$= n \log a$ ......(3)

If $y = \sqrt[m]{b}$

Then $\log y = \log \sqrt[m]{b}$
$= \frac{1}{m} \log b$ ......(4)

It is understood that base in all these expressions is 10. Obviously the multiplication and division are reduced respectively to the addition and subtraction of the logarithmic values. To find the result antilog tables are to be considered.

To find log of a quantity—It consists of two steps—(i) to write the characteristic, and (ii) to write the mantissa. Characteristic has to be written on the basis of understanding.

(i) In case of quantities greater than one, characteristic is one less than the number of digits. For example, characteristics of 4739, 473·9, 47·39 and 4·739 are 3, 2, 1 and 0 respectively.

(ii) In case of quantities less than one the characteristic is negative and it is numerically one more than the number of zeros following the decimal point on the right side. The negative nature of the characteristic is represented by the small horizontal line over the number expressing the characteristic. For example, characteristics of ·4739, ·04739, ·004739, ·0004739 are respectively $\bar{1}$, $\bar{2}$, $\bar{3}$, and $\bar{4}$.

Determination of mantissa—In fact log tables are used to determine mantissa. For all the numbers from 4739. . . ·0004739 the mantissa is the same and independent of the decimal point. First we locate the first two digits in the first vertical column. In our example we locate 47 andt hen in the horizontal to column of 47 we note down the number below the third digit. Here we shall note down the number below 3 which is ·6749 and then to this number we add the number given in the mean difference column below the fourth digit 9 in the horizontal column of 47 This number is 8 from the log table. Therefore, the mantissa for 4739 is (·6749+·0008 =·6757). When mantissa is known, it is combined with the characteristic to get the log of that quantity.

The following examples further explains the process of getting log for a quantity —

S. No.	Quantity	Characteristic	Mantisa (from log table)	log of the quantity
1	4739·0	3	·6749+·0008=·6757	3·6757
2	473·9	2	·6757	2·6757
3	47·39	1	·6757	1·6757
4	4·739	0	·6757	0 6757
5	·4739	$\bar{1}$	·6757	$\bar{1}$·6757
6	·04739	$\bar{2}$	·6757	$\bar{2}$·6757
7	·004739	$\bar{3}$	·6757	$\bar{3}$·6757
8	·0004739	$\bar{4}$	·6757	$\bar{4}$·6757
9	·00004739	$\bar{5}$	·6757	$\bar{5}$·6757

To find antilogarithm—For this process first mantissa is used. It is very similar to the process of taking the mantissa of a quantity. First in the antilogarithm table the first two digits of the mantissa are located and then the number in front of these

digits below the third digit are written. Finally the mean diff corresponding the fourth digit is added to the previously number. The decimal to this will be decided on the b the characteristic.

The following example gives the whole process.

$$Y = \frac{1000 \times 4 \times 980 \times 250}{3.142 \times (0.05)^2 \times 0.062}$$

$\log Y = \log (1000 + \log 4 + \log 980 + \log 250) - (\log 3.14$
$+ 2 \log 0.05 + \log 0.062)$

$\log 1000 = 3.0000$	$\log 3.142 = 0.4972$
$\log 4 = 0.6021$	$\log 0.05 = \overline{2}.6990$
$\log 980 = 2.9912$	$\log 0.05 = \overline{2}.6990$
$\log 250 = 2.3979$	$\log 0.062 = \overline{2}.7924$
Add $= 8.9912$	Add $= \overline{4}.6876$

$\overline{4}.6876$

Difference $= 12.3036$

$\log Y = 12.3036$

$Y = \text{Antilog } 12.3036$

$Y = 2.012 \times 10^{12}$ *dynes/sq. cm.*

Note:—Before using the logarithmic process of calculations, must solve for addition and subtraction and express quantities in decimal fraction.

Graph and its uses —In the study of certain physical phe menon a graph is plotted between the independent and depende variables always taking the independent variable along the X-a and dependent variable along the Y-axis. In plotting the gra the following points should be taken care of :—

(1) Suitable scales for independent and dependent variabl should be selected so that the full graph paper is used. Thes scales must be mentioned along the axis.

(2) The origin should be selected properly depending o whether variable quantities are both positive or one positive an another has negative value also. In case both are positive, th lower left corner can be taken as origin. If dependent variabl has negative values also, then middle point at the bottom should be taken as origin.

(3) The points on the graph paper are marked as dots or small circles etc. After marking all the points the smooth curve should be drawn which may pass through all the points or equal number of points exist on either side of it having about the same distance from the curve.

Graphs are used—(a) To prove certain laws, for example (i) a straight line plot between load and extension proves Hooke's law. (ii) a straight line plot between P and $\frac{1}{V}$ proves Boyle's law.

(b) To understand the dependence of dependent variable on independent variable. For example the straight line plot between resistance (R) and length of the wire (l) shows that resistance is directly proportional to the length of the wire.

(c) To find out certain variable quantities accurately. For example in the constant volume air thermometer experiment, two points are taken on the curve and β is calculated from these two values only. It is equivalent to calculating with different sets of observations and then averaging the results.

In the Newton's law of cooling experiment, rate of cooling is determined from the graph.

1

FRICTION

Friction—When a body is pulled over the surface of another body, an opposing force acts at the surface of contact. This opposing force is produced due to the roughness of the surfaces and it tends to stop the moving body. This property of the body is called *friction* and the force opposing the motion is known as the *force of friction*. The force of friction is always greater for dry surfaces.

Limiting Friction—When the pull to move a body on the surface of another is increased slowly then a stage is reached that the body just starts to move. This is known as the state of *limiting equilibrium* and the opposing force is called the *force of limiting friction*.

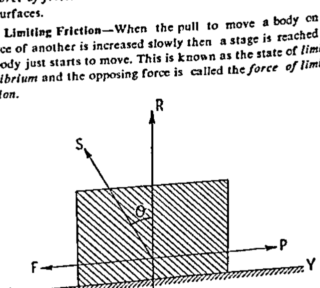


Fig. 1.1

Suppose a rectangular body is placed on a horizontal plane XY (Fig. 1·1). Its weight W acts in the downward direction and

the reaction of the plane 'R' in the upward direction, where $R=W$ according to the Newton's third law of motion. If parallel to the plane a pull P is applied to the body, the force of friction F acts opposite to P. But on increasing the pull P slowly a state is just reached when the body tends to move which is the state of limiting equilibrium. In this state the force of friction is maximum.

Let S be the resultant of the upward reaction R and limiting force of friction F, then the angle between S and R is known as the *angle of friction*. The ratio of the limiting force of friction F and the reaction R is called the coefficient of friction and generally written as μ.

$\therefore \quad \mu=\frac{F}{R}$

Since $\quad F=S\sin\phi$

and $\quad R=S\cos\phi$

Hence $\quad \tan\phi=\frac{F}{R}=\mu$

The limiting values of μ are—

$\mu=0$, for perfectly smooth surfaces,

$\mu=1$, for perfectly rough surfaces.

Laws of limiting friction

1. The force of friction acts in the direction opposite to the direction of motion.

2. The ratio of the limiting force of friction and the upward reaction is known as the coefficient of friction.

3. The coefficient of friction depends on the nature of the surfaces in contact and the upward reaction. It is independent of the shape and area of the surfaces.

EXPERIMENT 1·1

Object—To determine the coefficient of friction (μ) between two plane surfaces.

Apparatus—A wooden rectangular base having the plane glass top and at one side fitted with a smooth pulley, a rectangular wooden block fitted with one hook, thread, pan, weights and spirit level.

Formula

$$\mu = \frac{F}{R}$$

Where μ = coefficient of friction

F = Limiting force of friction

= Weight of the pan + weights placed in the pan

R = Normal reaction

= Weight of the rectangular wooden block + weigh placed on this block.

Method

1. First of all weigh the rectangular wooden block and th pan. Suppose their weights are M_1 and M_2 respectively.

2. *Level the apparatus with the help of the spirit level an make it horizontal. Then place the wooden block over it and ti the thread to its hook. Pass this thread over the pulley and faste the pan to the free end of the thread.*

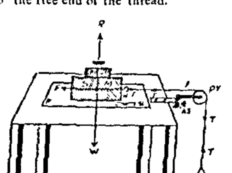


Fig. 1.2

3. Place a weight M_3 on the wooden block and then place some weight on the pan. Increase the weight in the pan gradually till the block *just starts to slide. Suppose the weights in the pan* are M_4.

4. Repeat the experiment *placing different weights on the* wooden block. It may also be *repeated using different wooden blocks.*

Observations

Weight of the wooden block $= M_1$ gm.

Weight of the pan $= M_3$ gm.

Serial No.	Weight placed on the block M_2 gm	Reaction $R=(M_1+M_2)$ gm	Weights placed on the pan M_3 gm	Force of friction $F(=M_3+M_4)$ gm	$\mu=\frac{F}{R}$
1					
2					
3					
4					
5					
6					

Average =

Calculations

$$\mu=\frac{F}{R}$$

Since, $F=(M_3+M_4)$ gm

and $R=(M_1+M_2)$ gm

$$\therefore \quad \mu=\frac{(M_3+M_4)}{(M_1+M_2)}$$

Result

Coefficient of friction between glass and wooden Surface $\mu=$

Standard $\mu=$

Percentage error= %

Precautions

1. The lower surface should be horizontal.
2. Pulley should offer least possible friction.
3. The thread from hook passing over the pulley should remain horizontal.
4. In case the experiment is repeated with different blocks, they should be equally rough and should be equally dry or moist.

EXPERIMENT 1.2

Object—To find out the coefficient of friction between two given surfaces with the help of inclined plane.

Apparatus—Adjustable inclined plane apparatus, a rectangular block of wood, weights and spirit level.

The apparatus consists of horizontal wooden base WB and there is another plane I P which is hinged at H and can be kept inclined in the vertical plane at any angle θ with the horizontal plane with the help of knob K and the circular scale CS. (Fig. 1·3)

Principle—We have already seen that the relation between the angle of friction and the coefficient of friction is

$$\mu = \tan\,\theta$$

If θ is determined we can find out μ with the help of the tangent tables. As shown in the Fig. 1.3, a wooden block of mass M_1 with a weight M_2 placed on it, i. e., the total weight $W = (M_1 + M_2)$ is placed on the plane IP and the inclination of IP is slowly increased till the wooden piece along with its weight can just slide. We can perform this experiment without placing any weight on the wooden block as well. In this limiting equilibrium state of friction, we have

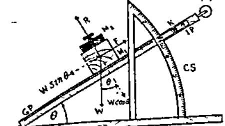


Fig. 1·3

$$F = W\,\sin\,\theta$$

$$\text{and} \quad R = W\,\cos\,\theta$$

$$\text{Hence} \quad \frac{F}{R} = \tan\,\theta$$

and we know from the definition

$$\mu = \frac{F}{R}$$

$$\therefore \quad \mu = \tan\,\theta$$

It is obvious that μ is independent of the weight of wooden block or any other weight if placed on it.

Method

1. Level the base WB with the help of the spirit level.

2. Place the wooden block on the inclined plane I P and adjust its inclination such that the block may start to slide downwards. If necessary tap the plane gently. Fix the inclination with the help of the knob K.

3. Read the angle of inclination with the help of the circular scale CS

4. Repeat the experiment after placing certain weights on the wooden block.

5. Repeat the experiment with other faces of the wooden block touching the plane I P.

Observations

Observation table

Serial No.	Angle of friction for first face θ_1	Angle of friction for second face θ_2	Average $\theta = \frac{\theta_1 + \theta_2}{2}$	$\mu = \tan\theta$
1				
2				
3				
4				

Average μ =

Result

Standard result =

Percentage error = %

Precautions

Same as in case of previous experiment

Oral questions

1. What is the limiting force of friction ?

2. What are the factors governing the limiting force of friction ?

3. State the laws of limiting friction

4. Explain the term normal reaction

5. Define the coefficient of friction

6. *Give some examples where you have realised the phe*menon of friction in daily life.

7. What is the importance of friction in daily life ?

8. What is the *practical importance of the study* of th coefficient of friction ?

9. Does the force of friction depend on the areas in contact

10. How does an error occur in the coefficient of friction the pulley is not perfectly smooth ?

11. Do you think that the pulley is completely smooth ? If no then what happens to your results ?

12. Define the angle of friction.

13. Does it depend on the normal reaction ?

2

YOUNG'S MODULUS OF ELASTICITY

Elasticity—A body, on the application of an external force, undergoes a change in its shape and size and on the withdrawal of the *deforming force* it regains its original position, then it is said to be *elastic*. This property of the matter is called *elasticity*. If on the withdrawal of the deforming force a body returns to its original position completely, it is said to be *perfectly elastic* and otherwise the deformed position is retained exactly, then the body is said to be *perfectly plastic*. Perfect elasticity and perfect plasticity are the two limiting cases and all the material bodies adjust between these two limits.

Strain—The internal force deforms a body. The deformation is considered relative to its original size and shape. Suppose a wire of original length L cm is increased in length by l cm by applying a force F. Then the strain is measured as the ratio of the increase in length to the original length.

$\therefore$ Longitudinal strain $= \frac{l}{L}$

Similarly a body of the original volume V c.c. undergoes a change of v c. c. in its volume on the application of an external force, then,

Volume strain $= \frac{v}{V}$

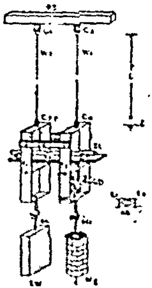
Obviously, the strain has no unit being the ratio of the two quantities of the same nature.

Stress—Whenever an external force is applied on a body, it is deformed and an internal reaction is developed within the body which tends to bring the body to its original position. The internal reaction is equal and opposite to the deforming force with in elastic

EXPERIMENT 2·1

Object—To determine the Young's modulus of a given wire.

Apparatus—A young's modulus apparatus, a metre scale, weights and a screw gauge.



W_1, W_2—Two wires of the same given metal

F_1, F_2—Rectangular metal frame

RS Common rigid support

SL – Spirit level

GD Circular scale

MS —Main scale

H_1, H_2—Hangers

SW —Weight suspended to straighten the wire W_2

L —Original length of the wire W_1 (outside C_1 and C_2)

Mg —Weight applied to the wire W_1

l —Increase in the length of W_1 produced by the weight Mg

Fig. 2·1

C_1, C_2, C_3, C_4— Chucks to hold the wires

CR—Common rod between the metal frames

Formula

(2) Put certain weight in the hanger of the experiment W_1 to remove kinks.

(3) Measure the length of the experimental wire W lower end of C_1 to upper end of C_4.

(4) Now adjust the circular scale to bring the bubble centre of the spirit level. Load the experimental wire in th of 1 Kg. With the help of the circular scale bring the bul centre of spirit level and take down the respective reading main scale as well as the circular scale. It can be loaded 6 kg.

(5) Unload the wire in the steps of 1 Kg. Adjust the level and take down the respective readings.

(6) Find out the mean reading for each load with the of the readings taken while the load increasing and decreasing

(7) Find out the increase in length for certain load ma use of observations in a systematic manner. For example, subt ting the readings for loads 1, 2, 3 Kg from those of 4, 5, 6 respectively. Thus three sets for increase in length for 3 Kg l are obtained. Calculate the mean value.

(8) Note down the pitch, least count and zero error of screw gauge. Measure the diameter of the experimental wire least at four different points and at evry point in mutually perpe cular directions. Calculate mean diameter and then find out radius of the wire.

(9) Finally calculate the Y using the formula.

Observations

Pitch of the spherometer = cm

Least count of the spherometer = cm

' length of the wire $L = 245$ cm

Observation table for extension of the wire (l)

S. No.	Load	Reading of micrometer screw							Extension
		Load increasing			Load decreasing			Mean reading	
		M.S.	C.S.	Total a	M.S.	C.S.	Total b	$\frac{a+b}{2}$	for 3 Kg.
1	1 Kg							A	
2	2 Kg							B	(D−A)= 0·136 cm.
3	3 Kg							C	(E−B)= 0·134 cm.
4	4 Kg							D	
5	5 Kg							E	(F−C)= 0·138 cm.
6	6 Kg							F	

Mean extension = *0·136 cm*
for 3 Kg

Observations for radius of the wire.

Pitch of the screw gauge = cm

Least count of the screw = cm

Zero error the screw gauge =

Observation table for radius of wire (r)

S. No.	Reading in one direction			Reading in ⊥ direction			Mean diameter
	M.S.	C.S.	Corrected diameter A	M.S.	C.S.	Corrected diameter B	$\frac{A+B}{2}$
1.							
2.							
3.							
4.							
5.							
6.							
7.							

Mean diameter = 0·084 cm

∴ Average r = 0·042 cm

Calculations

$$Y = \frac{MgL}{\pi r^2 l}$$

$$= \frac{3000 \times 980 \times 245 \times 7}{22 \times \cdot 042 \times \cdot 042 \times \cdot 136}$$

$$= \left(\frac{3 \times 98 \times 245 \times 7}{22 \times 42 \times 42 \times 1 \cdot 36}\right) \times 10^{11}$$

$$= X \times 10^{11}$$

X stands for the quantity inside the bracket.

$\log 3 = 0 \cdot 4771$	$\log 22 = 1 \cdot 5424$
$\log 98 = 1 \cdot 9912$	$2 \log 42 = 3 \cdot 2464$
$\log 245 = 2 \cdot 3892$	$\log 1 \cdot 36 = 0 \cdot 1335$
$\log 7 = 0 \cdot 8451$	Add $= 4 \cdot 7223$
Add $= 5 \cdot 7026$	
$4 \cdot 7223$	
Diff. $= 0 \cdot 9803$	

Antilog $0 \cdot 9803 = 9 \cdot 557$

$\therefore$ $Y = 9 \cdot 557 \times 10^{11}$ dynes/sq. cm.

Result—Young's modulus for brass, $Y = 9 \cdot 557 \times 10^{11}$ dynes/sq.cm.

Standard result, $Y = 9 \cdot 9 \times 10^{11}$ dynes/sq. cm.

Percentage error = %

Precautions—(1) There should be no kinks in the wire.

(2) Wire should be loaded and unloaded gently and some e should be given before taking the observations.

(3) Load should not increase more than half the breaking l.

(4) Bubble should be brought in the centre of the spirit level re taking the readings.

(5) Reading for radius should be taken more carefully as its re appears in the formula.

EXPERIMENT 2.2

Object—*Verify Hooke's law*

Apparatus—Young's modulus apparatus, loads.

It can also be proved by showing that

Load $\propto$ extension

Method—Same as in the experiment 2.1 except that the radius of the wire and extension for certain fixed load need not be found out.

Observations

Observation table for Hooke's law verification.

S. No.	Load	Reading of micrometer screw							
		Load increasing			Load decreasing			Mean reading	Extension in cm
		M.S.	C.S.	Total a	M.S.	C.S.	Total b	$\frac{a+b}{2}$	
1	0 Kg.							A	(B − A) = 0·136
2	1 Kg.							B	(C − A) = 0·273
3	2 Kg.							C	(D − A) = 0·405
4	3 Kg.							D	(E − A) = 0·545
5	4 Kg.							E	(F − A) = 0·684
6	5 Kg.							F	(G − F) = 0·818
7	6 Kg.							G	

A graph is plotted between the load and extension taking

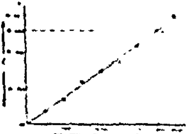


Fig. 2.2

load along the X-axis and extension along the Y-axis a straight line is obtained as shown in the fig. 2.2

Result—The graph plotted between load and extension comes to be a straight line which proves the Hooke's law.

Precautions—*Same as in experiment 2.1*

Oral questions

(1) Explain elasticity, coefficient of elasticity, elastic limit and elastic fatique.

(2) Define strain, stress and Young's modulus of elasticity and mention their respective units.

(3) State Hooke's law and how will you prove it.

(4) Explain why two similar wires are used in the Young's modulus apparatus ?

(5) Which is more elastic, rubber or steel ?

(6) What is the significance of Young's modulus in practical life.

(7) Explain why do you use the micrometer screw to measure the extension while the metre scale or tap for measuring the length of the wire ?

(8) Why do you measure the radius of the wire more accurately ?

(9) Explain the terms—Pitch, least count, zero error and back:lash error.

(10) How do you eliminate the backlash error ?

3

BOYLE'S LAW

The study of the gaseous state of matter is in fact the study of variation of its volume, pressure and temperature in a systematic manner. Every gas below the critical temperature is known as vapour and it is liable to condense if pressure is increased. It was Boyle who first made a systematic study of the dependence of the volume of a given mass of a gas on its pressure when temperature remains constant and the relation observed by him is known as Boyle's law. His observation is not true for vapour state.

Boyle's law states "The volume of a given mass of a gas at constant temperature is inversely proportional to its pressure."

If P and V are the pressure and volume of a given mass of a gas at a constant temperature T, then according to Boyle's law, we have

$$P \propto \frac{1}{V}$$

or $$P = K\frac{1}{V}$$

or $$PV = K \text{ (constant)}$$

When the pressure of the gas is varied isothermally, i. e., by maintaining the constant temperature, the volume also changes and according to Boyle's law, we have the following relation—

$$P_1V_1 = P_2V_2 = P_3V_3 = \ldots\ldots\ldots\ldots\ldots = K \text{ (constant)}$$

Where P_1, P_2, P_3 are the different pressures and V_1, V_2, V_3 are the corresponding volumes of the gas.

Limitations of Boyle's law

1. Boyle's law is accurate at low pressures and does not hold true at very high pressures.

2. *For ordinary gases it is accurate at a certain temperature known as Boyle's temperature. Boyle's temperature is three times the critical temperature for a gas.*

3. Vapours do not obey Boyle's law. If water vapours are present in any gas, on increasing the pressure the gas may be *saturated with water vapours.*

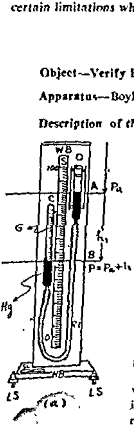
For ideal gases the Boyle's law is vigorously true for all ranges of temperature and pressure but real gases suffer from *certain limitations which have been pointed out above in short.*

EXPERIMENT 3·1

Object—Verify Boyle's law.

Apparatus—Boyle's law apparatus, a barometer etc.

Description of the Boyle's law apparatus—It consists of a vertical wooden stand fitted with a metre scale *S as shown in the Fig. 3·1 and there* are two slots on either side of the scale. In one slot there is fitted a tube C graduated in cubic centimetres with its upper end closed. In another slot there is fitted an open tube O. *The tube O can be slided* up and down in the slot. Both the glass tubes are connected by rubber tubing R T. The rubber tubing and *a part of tubes O* and C contain pure mercury. There is dry *air enclosed in the* upper portion of the tube C. The base of the apparatus is fitted with three levelling screws to make *the scale perfectly vertical.*



Theory—*Boyle's law states* that the volume of a given mass of *a gas varies inversely to its pressure when temperature* remains constant.

Let P and V be the pressure and the volume of a given mass of a gas respectively.

$$\therefore P \propto \frac{1}{V}$$

or $PV = \text{constant (k)}$

Hence according to Boyle's law

$$P_1V_1 = P_2V_2 = P_nV_n = \ldots\ldots\ldots K$$

If the gas is enclosed in a tube of uniform cross-section $V \propto l$ where l is the length of the air column.

Therefore, according to Boyle's law, we have

$P_1l_1 = P_2l_2 = P_3l_3 = \ldots \ldots$

and $\qquad P \propto \frac{1}{l}$

Method

1. Read the atmospheric pressure and the room temperature with the help of a barometer and a thermometer respectively.

2. Make the apparatus perfectly vertical with the help of levelling screws and raise the open tube O to a convenient height as shown in (fig. 3 1). Now take down the readings of the upper end of the tube C and the positions of convex meniscus of mercury in both the tubes C and O If C is graduated, the volume of the gas can be read directly.

3. Note the difference of the closed end of C and the convex meniscus of mercury in C which gives l, i.e., the height of the column of gas.

4. Note down the difference of mercury meniscus in the tubes C and O and let it be h. As it is clear from the fig. 3 1 the pressure of the gas is greater than that of atmosphere by h. Therefore the gas pressure P = atmospheric pressure $P_a + h$

5. Slowly slide the tube O downwards in steps and take down at least six readings with the gas pressure greater than that of atmosphere.

6. Then slide the tube O in such a way that the mercury level in O is lower than that of C and in these cases the gas pressure is less than that of atmosphere as shown in the fig. 3·2. Take down at least six readings when the gas pressure is less than the atmospheric pressure. In these cases the gas pressure P = atmospheric pressure $P_a - h$.

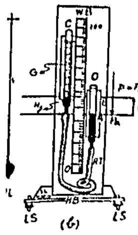


Fig 3·2

7. Again read the atmospheric pressure and the room temperature at the end of the experiment.

Observations

Atmospheric pressure in the beginning	=	cm
" " in the end	=	cm
Mean atmospheric pressure P_a	=	
Room temperature in the beginning	=	
" " in the end	=	

Calculations

Result—The product P V is constant which proves the law.

In case the tube C is not graduated in c.c. the graph between P and $\frac{1}{l}$ is plotted.

When a graph between P and $\frac{1}{V}$ is drawn it comes to be a straight line as shown in the fig. 3·3 which further verifies the Boyle's law.

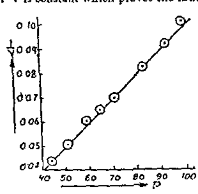


Fig. 3·3

Precautions

1. Some time should be given before taking each reading to ensure the change to be isothermal.

2. The mercurry level should be read for the highest point of the convex meniscus.

EXPERIMENT 3·2

Object—To find out the atmospheric pressure using the Boyle's law apparatus.

Apparatus—Same as in the previous experiment.

Theory—(i) From Boyle's law, we have

$$P_1V_1 = P_2V_2$$

Where P_1 and P_2 are $(P_a \pm h_1)$ and $(P_a \pm h_2)$ respectively

Therefore,

$$(P_a \pm h_1)V_1 = (P_a \pm h_2)V_2$$

If h is positive on both sides, then

$$(P_a + h_1)\,V_1 = (P_a + h_2)V_2$$

or $\quad P_a\,(V_1 - V_2) = h_2V_2 - h_1V_1$

or $\quad P_a = \dfrac{h_2V_2 - h_1V_1}{V_1 - V_2}$

Similarly P_a can be calculated from different sets of readings.

(ii) By plotting the graph—If we plot the graph with a suitable scale taking h along the X-axis and $\frac{1}{V}$ along the Y-axis we obtain a straight line as shown in the fig. 3·4

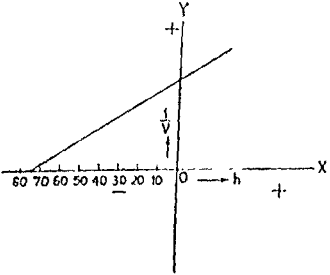


Fig 3·4

The intercept on the X axis gives the atmospheric pressure

Method—Same as in the previous experiment.

Observations

Readings of the upper closed end of C= cm

S No	Mercury level in C	Mercury level in O	Difference of levels in C and O (h)	Volume of the gas V	$\frac{1}{V}$
1					
2.					
3					
4.					
5.					
6.					

Calculations

Result -

Atmospheric pressure	=	cm
Correct result at that place (From barometer)	=	cm
Percentage error	=	%

Precautions—Same as in the previous experiment.

Oral questions

1. Explain Boyle's law.
2. Point out the limitations of Boyle's law.
3. What is an isothermal change? Give some examples of such changes.
4. What do you understand by ideal gas and real gas?
5. What is the difference between a gas and a vapour?
6. Explain the critical temperature of a gas.
7. If there is water vapour in a closed tube, will the Boyle's law hold true?
8. Define pressure and mention its unit.
9. What is atmospheric pressure? How do you express it?
10. How will you express it in usual units of pressure?
11. How do you find the pressure of the gas enclosed in the Boyle's law apparatus?

Why mercury is preferred in the Boyle's law apparatus over other liquids?

. How do you ensure the change to be isothermal in your experiment?

. Explain adiabatic change and give some examples of it.

. What do you understand by Boyle's temperature? What is its significance?

Procedure

1. Put sufficient water in the boiler and put it on the burner or heater.

2. Make the electric connections as shown in the figures 4·1 and 4·2.

3. Note down the pitch and the least count of the spherometer.

4. Measure the length of the experimental rod.

5. Put a thermometer through the cork in the jacket just to make its bulb touching the rod and note down initial temperature.

6. Take the initial reading of the spherometer when its middle leg is made to touch the free end of the rod. The contact is ensured by the deflection in the voltmeter. Read this setting repeatedly and record in the table. Rotate the spherometer such that the free end can expand freely.

7. Now pass the steam in the jacket and wait till the temperature of the rod becomes constant. Note down the temperature.

8. Take the final reading with spherometer and repeat it number of times.

9. Find out the mean expansion of the rod and calculate for α.

Observations

Initial length of the rod at room temperature = cm
Initial temperature = °C
Pitch of the spherometer = cm
Least count = cm
Final temperature = °C

Observation table for expansion

S. No.	Initial reading of the micrometer			Final reading of the micrometer			Expansion in length b—a
	M. S.	C. S.	Total reading a	M. S.	C.S.	Total reading b	
1.							
2.							
3.							
4.							

Mean expansion =

Calculations

$$\alpha = \frac{L_2 - L_1}{L_1 (t_2 - t_1)}$$

$$\alpha = \frac{0.065}{50.1 \times (98.5^\circ - 30^\circ)} \qquad \text{Since } L_2 - L_1 = 0.065 \text{ cm and } L_1 = 50.1 \text{ cm}$$

$$\alpha = \frac{0.065}{50.1 \times 68.5}$$

$\log 0.065 = \bar{2}.8129$	$\log 50.1 = 1.6998$
3.5355	$\log 68.5 = 1.8357$
Diff. $= \bar{5}.2774$	Add $= 3.5355$

$\log \alpha = \bar{5}.2774$

$\therefore \quad \alpha = \text{antilog } \bar{5}.2774$

or $\quad \alpha = 0.0000167$ per degree centigrade

Result

Standard result =

Percentage error =

Precautions

1. There should be taken sufficient water in the boiler.

2. Rubber tubings should be properly placed to avoid the collection of condensed water in them.

3. The end of the exit rubber tube should be dipped in water so that steam coming from the jacket may be condensed.

4. Spherometer reading should be taken when contact is ensured by deflection in the voltmeter.

5. Back lash error should be avoided.

6. For final reading the temperature should be constant for 10 minutes.

Oral Questions

1. Define the coefficient of linear expansion and mention its unit.

2. Why do you use spherometer to find the expansion in length ?

3. What is the use of electric circuit in this experiment.

4. What is the practical importance of the knowledge of coefficient of linear expansion ?

5. Why some space is left between two pieces of rail ?

is experiment ?

5

THERMAL EXPASI OF LIQU

In general all liquids expand on heating except water bet *O°C and 4°C and some aqueous solutions. Liquids do not have* own shape but they acquire the shape of the containers conta them. The cubical expansion of liquid, in general, consid *relative to the container. If we neglect the expansion of* container, the expansion of liquid is apparent expan which is less than the true expansion. When account is take *the expansion of the container, then it is called the real ex* sion. Thus there are two distinct coefficients of cubical expans of liquids.

Coefficient of apparent expansion

It is defined as the apparent increase in volume per u volume per degree rise in temperature when the liquid is heated *a container which expands on heating. It is represented by C_a .*

Coefficient of real expansion

It is defined as the actual increase in volume per unit volum per unit degree rise in temperature. It is represented by C_r .

C_r is greater than C_a by the coefficient of cubical expansion of the material of the container. If liquid is contained in a glass vessel and coefficient of cubical expansion of glass is C_g , then

$$C_r = C_a + C_g ,$$

EXPERIMENT 5.1

Object—To determine the coefficient of apparent cubical expansion of a liquid using a weight thermometer*.

Apparatus—A weight thermometer, liquid, thermometer, a balance, weight box, water bath, burner or heater etc.

Formula $$C_a = \frac{m}{M_t \times t}$$

Where C_a = Coefficient of apparent expansion

m = mass of liquid expelled from the weight thermometer on heating up to constant temperature (temperature of boiling water).

M_t = Mass of liquid left in the weight thermometer at the boiling temperature of water.

t = difference of temperature of the boiling water and room temperature.

Procedure

1. Wash the weight thermometer with nitric acid, dry it and then weigh it empty.

2. To fill the liquid in the weight thermometer, suspend it from a thread and dip its mouth in the hot liquid contained in a beaker as shown in the fig. 5.1. Now heat the weight thermometer so that air inside it will expand and will go out. On cooling the air inside it contracts and the liquid rushes in.

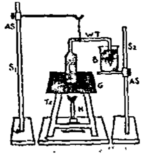


Fig. 5·1

**The specific gravity bottle may be used in place of a weight thermometer and in working it is very conveninet.*

3. Again heat it so *that some air will go out and on cooling* more liquid will rush into the weight thermometer.

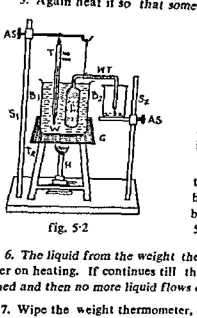


fig. 5·2

4. By alternate heating and cooling fill the weight *thermometer completely* with the liquid at the room tempe*rature. Wipe it* and *find* out its mass with liquid.

5. *Suspend* the *weight* thermometer in the *water* bath with its mouth *inside* beaker as shown in the fig. 5.2 and then heat it.

6. The liquid from the weight thermometer comes out in the beaker on heating. If continues till the boiling point of water is *reached and then no more liquid flows out.*

7. Wipe the weight thermometer, cool it and then weigh it.

8. Take down the room temperature. It is better if it is *taken at the beginning of the experiment also.*

9. Calculate the coefficient of apparent cubical expansion of the given liquid.

Observations

1. Mass of the empty weight *thermometer*	=	gm
2. Mass of the weight thermometer filled with liquid at room temperature	=	gm
3. Mass of the weight thermometer filled with liquid at boiling point of water	=	gm
4. Room temp. at *the beginning of the experiment*	=	°C
5. Room temp. at the end of the experiment	=	°C
6. Boiling point of water	=	°C

Calculations

$$C_a = \frac{1.545}{51.260 \times 73.5}$$

$\therefore \log C_a = (\log 1.545) - (\log 51.260 + \log 73.5)$

$\log 1.545 = 0.1889$	$\log 51.26 = 1.7098$
3.5761	$\log 73.5 = 1.8663$
Diff. $= \bar{4}.6128$	Add $= 3.5761$
$\log C_a = \bar{4}.6123$	

$C_a = \text{Antilog } \bar{4}.6128$

$= 0.0004101$ per °C

Result

Coefficient of apparent cubical expansion

of the given liquid =

Standard result =

Percentage error = %

Precautions

1. Air bubbles should be removed from the weight thermometer.

2. Liquid should be heated before filling to save the weight thermometer from cracking.

3. Weight thermometer should be handled gently.

4. In transit no liquid should come out of the weight thermometer

Oral Questions

1. Define the coefficient of apparent cubical expansion and mention its unit.

2. How do you relate the coefficient of apparent expansion to that of real expansion ?

3. Why do you call it weight thermometer ?

4. Can you find out C_a of all liquids by this ?

5. Does a liquid expand uniformly at all temperatures ?

6. What is the pratical application of the knowledge of thermal expansion of liquid ?

Note—The same experiment can be performed with the help of a specific gravity bottle and it is easier to fill the liquid in

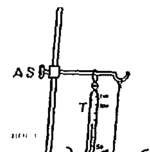


Fig. 5·3

this bottle than in the weight thermometer. We need not heat and cool it alternately to fill the liquid. Rest of the procedure is the same. Specific gravity bottle is shown in the fig. 5.3 when it is heated to expell the liquid out of it at the boiling temp. of water.

6

CONSTANT VOLUME GAS THERMOMETER

The state of a gas is characterised by three quantities, viz, its pressure P, volume V and temperature T. These quantities are inter-dependent and their dependence is studied by keeping one of them constant and varying the second to study the variation of the third. Here the volume of a given mass of a gas is kept constant and by varying the temperature the variation in pressure is studied which gives the law of pressure.

The variation of pressure of a given mass of a gas is uniform with respect to temperature when volume is kept constant. This property is used for measuring temperatures hence the apparatus to study the variation of pressure with respect to temperature when volume is kept constant is called constant volume gas thermometer

Pressure coefficient

It is defined as the ratio of the increase in pressure of the gas at constant volume, per degree rise of temperature, to its pressure at o°C. If P_o and P be the pressure of a given mass of a gas, keeping its volume constant, at o°C and t°C respectively, then

$$P = P_o\,(1+\beta t)$$

Where β = pressure coefficient

$$\beta = \frac{P-P_o}{P_o \times t}$$

EXPERIMENT 6·1

Object—Study the variation of pressure with temperature using constant volume air thermometer and determine the pressure coefficient of air.

Apparatus—Constant volume air thermometer, ordinary thermometer, tripod stand, water bath, stirrer, wire gauge, burner etc.

2. Immerse the glass bulb G B completely in the water inside beaker B as shown in the fig. 6.1 and read the initial temperature (room temperature) after stirring the water.

3. To keep the volume of air constant fix a mark and it is M in case of fig. 6.1

4. Read the atmospheric pressure with the help of a Fortin's barometer correct up to mm.

5. Read the mercury level in the tube O T at room temperature.

6. Now heat the water in the beaker B with the help of burner or heater or whatever heating device is provided in the laboratory till water starts boiling. Stir it thoroughly and after 5 minutes when temperature has become constant adjust the position of the tube O T such that mercury level in capillary tube stands against the mark M. Then read the mercury level in O T and temperature of boiling water.

7. To cool the water in the beaker B put off the burner. Stir it well and after the interval of every 5°C take down the reading of mercury level in open tube O T after adjusting its position to bring the mercury level in the capilliary against M.

8. Read the barometer in the end also.

9. Find out the difference for mercury level in case of every observation and by adding it to the atmospheric pressure. Obtain the pressure exerted by air enclosed in G B.

10. Plot a graph between temperature and air pressure and select two suitable points on the graph to calculate β. With the help of these values calculate β.

Observations

Atmospheric pressure at the beginning of experiment	—	cm
" " " end	—	cm
Average atmospheric pressure P_a	—	cm

Description of constant volume air thermometer

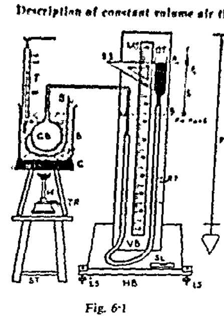


Fig. 6·1

It consists of a glass bulb G B as shown in the figure 6.1. Glass bulb is connected to a thick capillary tube bent twice at right angles. There is glass tube OT fitted to a vertical stand and can be moved up and down. *O T is con*nected to the capillary tube through a rubber *tubing R T. Glass bulb and* part of capillary tube is filled with air and tube *O T and rubber tubing RT* contain mercury. The base of the vertical stand is *fitted with levelling screws* and there a scale fitted to the vertical stand.

Theory

At the constant volume the ratio of the increase in pressure of a given mass of a gas for the rise of 1°C to its pressure at O°C is defined as pressure coefficient. It is measured with the *following formula*

$$\beta = \frac{P - P_o}{P_o \times t}$$

Obviously the pressure of the gas is measured at o°C and t°C It is more *convenient* to take the room temperature and the temperature of boiling water *or any pair of temperatures selected* between these two temperatures.

Since $P_1 = P_o (1 + \beta t_1)$ ......(1)

Or $P_2 = P_o (1 + \beta t_2)$ ......(2)

From (1) and (2) we obtain

$$\beta = \frac{P_2 - P_1}{P_1 t_2 - P_2 t_1}$$

Procedure

$$= \frac{86.4 - 70.4}{70.4 \times 98 - 86.4 \times 31}$$

$$= \frac{16}{70.4 \times 98 - 86.4 \times 31}$$

log 70·4 = 1·8482	log 86·4 = 1·9370
log 98 = 1·9912	log 31 = 1·4914
Add X = 3·8394	Add Y = 3·4284
Antilog X = 6908·0	Antilog Y = 2681·0

$$\therefore \quad \beta = \frac{16}{6908 - 2681}$$

$$= \frac{16}{4227}$$

$$\log \beta = \log 16 - \log 4227$$
$$= 1.2041 - 3.6260$$
$$= \bar{3}.5781$$

$$\therefore \quad \beta = \text{Antilog } \bar{3}.5781$$
$$= 0.003785 \ / \ ^\circ C$$

2. $$\beta = \frac{P_{100} - P_o}{P_o \times 100}$$

$$= \frac{87.5 - 64.1}{64.1 \times 100}$$

$$= \frac{23.4}{6410}$$

$$\log \beta = \log 23.4 - \log 6410$$
$$= 1.3692 - 3.8069$$
$$= \bar{3}.5623$$

$$\therefore \quad \beta = \text{Antilog } \bar{3}.5623$$
$$= 0.003663 \ / \ ^\circ C$$

Result

Pressure coefficient of air = / °C

Standard result =

Percentage error = %

Precautions

1. The glass bulb G B should contain dry air.

2. The mercury used should be pure and dry and should not stick to the sides of the apparatus. There should be no traces of mercury in the glass bulb.

...rvation table

Temperature of water in beaker B	Fixed point M for mercury level in the capillary tube	Mercury level in O T	Difference of H_g levels (h)	Air pressure $P = P_a + h$
...0°C	cm.	cm.	cm.	cm.

Calculations—Plot a graph between temperature and air pressure taking temperature along the X-axis and air pressure along the Y-axis. As shown in the figure 6·2 it comes to be a straight line which shows that air pressure is directly proportional to the temperature when volume of the given mass of a gas (air) is kept constant.

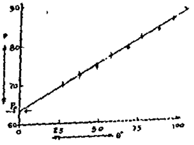


Fig. 6·2

From the graph select any two suitable points which can be 0°C and boiling point of water and find out the corresponding values from the graph and calculate β.

Any other two points except 0°C and boiling point of water ...y be taken but they should be far ap...

2. To calculate melting point of wax, we have to measure the air pressure at 0°C, boiling point of water, i. e., at 100°C and at the melting point of wax which are P_o, P_{100} and P respectively. Then with the help of the formula given above the melting point of wax can be determined.

P_o and P_{100} can be obtained from graph also.

Observations

Same as in experiment 6·1 plus additional observations for air pressure at 0°C and boiling point of water and melting point of wax.

P_o and P_{100} can also be obtained from the graph.

Calculations

(i) Plot the graph as described already.

(ii) $$t = \frac{P - P_c}{P_{100} - P_o} \times 100$$

Result

Standard result

Percentage error

Precautions

Same as in experiment 6 1

Oral Questions

1. Define the pressure coefficient. Mention its unit. What is its value for perfect gases ?

2. Why do you insist to fill the dry air in the glass bulb of the constant volume air thermometer ?

3. What are the advantages of mercury used in a gas thermometer ?

4. Can we use water for mercury ?

5. How do you keep the volume of the gas constant ?

6. How will you measure the melting point of wax by the gas thermometer ?

7. Can we measure the temperature of human body by this thermometer ?

8. What is the relation between pressure and temperature of a given mass of a gas at constant volume ?

9. What are the important precautions ?

10. Explain the absolute zero.

3. The glass bulb should be completely immersed in water in the beaker B and should be stirred well before each reading.

4. While cooling the gas the open tube should be lowered so that on contraction of air on cooling mercury may not rush into the glass bulb G B.

5. The reading for temperatures between room temperature and boiling point of water should be taken while cooling the air in G B.

EXPERIMENT 6·2

Object–To measure the melting point of wax using the constant volume air thermometer.

Apparatus—Same as in the experiment 6·1.

Theory—The melting point of wax can be determined either (i) with the help of the graph plotted between the temperature and pressure, or (ii) it can be calculated by the following formula also

$$t = \frac{P - P_o}{P_{100} - P_o} \times 100$$

Where P_o = Air pressure at 0°C

P_{100} = Air pressure at boiling point of water

P = Air pressure at melting point of wax.

t = Melting point of wax

Procedure

1. The experiment is performed as described in experiment 6·1 and graph between temperature and air pressure is also plotted as already described.

To measure the melting point of wax the glass bulb GB is immersed in a container full of wax. The container is heated and when wax starts to melt the open tube O T is so adjusted that mercury in the capillary stands against the fixed mark M. The observation of mercury level in OT is taken. When all the wax melted then it is permitted to solidify. Again when wax starts to solidify the open tube OT is so adjusted that mercury level in the capillary stands against the fixed mark M. The mercury level in OT is noted. Hence P the air pressure at melting point of wax is found. From the graph, the temperatu[illegible] corresponding to [illegible] gives the melting point of wax.

2. To calculate melting point of wax, we have to measure the air pressure at 0°C, boiling point of water, i. e., at 100°C and at the melting point of wax which are P_o, P_{100} and P respectively Then with the help of the formula given above the melting point of wax can be determined.

P_o and P_{100} can be obtained from graph also.

Observations

Same as in experiment 6·1 plus additional observations for air pressure at 0°C and boiling point of water and melting point of wax.

P_o and P_{100} can also be obtained from the graph.

Calculations

(i) Plot the graph as described already.

(ii) $$t = \frac{P - P_o}{P_{100} - P_o} \times 100$$

Result

Standard result

Percentage error

Precautions

Same as in experiment 6 1

Oral Questions

1. Define the pressure coefficient. Mention its unit. What is its ... ect gases ?

... to fill the dry air in the glass bulb of ... ter ?

... of mercury used in a gas thermo-

7

THERMAL CONDUCTIVITY

EXPERIMENT 7.1

Object—*To determine the thermal conductivity of a good conductor given in the form of a cylindrical bar.*

Apparatus—Searle's apparatus, four thermometers, a boiler, measuring flask, vernier calliperse, metre scale, weight box, stop watch, burner etc.

Description of Searle's apparatus

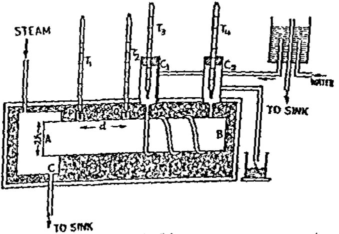


Fig. 7·1

A B is a metal rod whose coefficient of thermal conductivity ... ...mined. The end A is enclosed in a steam chamber

in which steam can continuously be passed. The other end B is surrounded by the thin copper tubing in the form of spiral. Each end of this spiral terminates in the form of a cup and a thermometer is fitted in each of them through corks as shown in the fig.7.1. Two thermometers T_1 and T_2 are fitted into two holes in the rod A B at the points P and Q and in some good apparatus the bulbs of thermometers are in contact with rod by dipping them in mercury contained in small holes at P and Q which are at a distance of d cm. This whole system is enclosed in a wooden box which is packed with cotten wool.

Theory

The end A is heated by passing steam continuously in the chamber C. Heat flows through the rod A B towards the end B. The temperature of thermometers at P and Q rises continuously. A constant flow of water is maintained in the copper spiral tubing. The temperature of inflowing and out-flowing water is recorded by the thermometers T_3 and T_4 respectively.

When steady state of temperature is reached, all the four thermometers record constant temperatures. The amount of heat flowing through the bar per second is absorbed by the circulating water at the end B. Let m gm. be the mass of water flowing in t seconds and θ_3 and θ_4 be the temperatures recorded by the thermometers T_3 and T_4 fitted in the cups C_1 and C_2 at the entrance and exit of the spiral tubing respectively.

The heat taken up by water per second

$$Q=\frac{m}{t}\ (\theta_4-\theta_3) \qquad \ldots\ldots(1)$$

But the amount of heat Q flowing per second through the bar is given by

$$Q= K.\,a.\ \frac{(\theta_1-\theta_2)}{d} \qquad \ldots\ldots(2)$$

Where K= the coefficient of thermal conductivity

a= area of cross-section of the rod A B

θ_1 and θ_2 are temperatures recorded by thermometers at P and Q at a distance of d cm.

Equating (1) and (2), we have

$$K.\ a.\ \frac{(\theta_1-\theta_2)}{d} = \frac{m}{t}.(\theta_4-\theta_3) \quad ..$$

$$\text{or}\quad K = \frac{m\ (\theta_4-\theta_3)\ d}{t.\ a.(\theta_1-\theta_2)} \quad ...$$

Coefficient of thermal conductivity

It is defined as the quantity of heat flowing per se through unit area of cross-section of an element of the materi unit thickness, when the difference of temperature betwee faces is unity. In C. G. S. system its unit is **calories per sec. sq. cm. per temperature gradient of 1°C per cm.** Its dimens are $M^1 L^1 T^{-3} \theta^{-1}$.

Procedure

1. Measure the diameter of the experimental rod at fou five points with the help of a vernier calliperse.

2. Measure the distance d between the points P and Q wit metre scale.

3. Carefully insert the thermometer T_1, T_2, T_3 and T_4.

4. Pass the steam in the steam chamber C from a boiler.

5. The inlet of the copper tubing is connected to a consta level water reservoir to have a constant flow of water throug spiral.

6. When steady state of temperature is reached, wait for 5 10 minutes and then note down the temperatures θ_1, θ_2, θ_3 and θ from the thermometers T_1, T_2, T_3 and T_4 respectively.

7. Quantity of water flowing out in a known time t secon is collected in a clean beaker. Measure its volume by a measuring flask.

8. Calculate K with the help of the formula (4).

S. No.	M. S. reading	Vernier Scale reading	Diameter of the rod
1			
2			
3			
4			
5			

Mean value of diameter cm

1. radius of the rod r = cm
2. The distance between T_1 and T_2, d — cm
3. Temperature recorded by thermometer T_1, θ_1 = °C
4. " " " T_2, θ_2 = °C
5. " " " T_3, θ_3 = °C
6. " " " T_4, θ_4 = °C
7. Volume of water collected inside the beaker c.c
8. Time for which water is collected, t sec

Calculations

Mass of water collected gm

$$K = \left(\frac{m}{t}\right)\frac{(\theta_1-\theta_2)\,d}{\pi r^2(\theta_3-\theta_4)}$$

If $\frac{m}{t} = 1.3$ gm / sec.

$$\therefore \quad K = \frac{1.3\,(35.6-30.2)\times 9.53}{3.142\times 1.26\times 1.26\times(56.2-40.6)}$$

$$= \frac{1.3\times 5.4\times 9.53}{3.142\times 1.26\times 1.26\times 15.6}$$

log 1.3 = 0.1139
log 5.4 = 0.7324
log 9.53 = 0.9791
Add = 1.8254
= 1.8911
Diff. = $\bar{1}$.9343

log 3.142 = 0.4972
log 1.26 = 0.1004
log 1.26 = 0.1004
log 15.6 = 1.1931
Add = 1.8911

Antilog $\bar{1}$.9343 = 0.8596

Result

The coefficient of thermal conductivity of a rod of a given metal=0.8596 calories/sec/sq.cm/1°C/cm.

Standard result =

Percentage error=

Percautions

1. The thermometers T_1 and T_2 must touch the rod or contact can be ensured by putting some mercury in the small holes drilled at the points P and Q.

2. The thermometers T_3 and T_4 should be inserted into the cups C_1 and C_2 up to the extent that they are well in water.

3. More accurate thermometers having the least count 0.2°C should be used.

4. The flow of water through the spiral should be sufficiently slow and regular.

5. Temperatures should be recorded after 5 to 10 minutes of reaching in the steady state of temperature.

Oral Questions

1. Define the coefficient of thermal conductivity. State its unit and dimensions.

2. Explain the steady state of temperature.

3. Why the box is packed with cotton and wool ?

4. Explain the phenomenon of conduction of heat ?

5. Why the flow of water in the spiral is required to be very slow.

6. What are the possible sources of error in this experiment ?

8

NEWTON'S LAW OF COOLING

When a hot body is left to cool, it loses its heat by the process of radiation, convection and conduction. In case the process of radiation is significant and losses due to conduction and convection are negligible the Newton's law of cooling holds true provided the difference between the temperature of the hot body and that of surroundings does not exceed 60°C or 70°C. It is a special case of more general law, i. e., the Stefan's law which is true for all ranges of temperature difference between the hot body and the surroundings.

Newton's law of cooling

It state that rate of cooling of a body is directly proportional to the excess of its temperature over that of surroundings provided the excess is not large. In short we can write—

Rate of cooling ∝ excess of temperature

Suppose the temperature of a body falls from θ_1 to θ_2 in t seconds and the temperature of the surroundings is θ

$$\text{Rate of cooling} = \frac{w(\theta_1 - \theta_2)}{t} \text{ calories per sec}$$

where w is the thermal capacity of the body

The average temperature of the body during this interval of t seconds $= \left(\frac{\theta_1 + \theta_2}{2}\right)$°C

$$\text{The excess of temperature} = \left(\frac{\theta_1 + \theta_2}{2} - \theta\right)°C$$

∴ According to Newton's law of cooling, we have

$$\frac{W(\theta_1 - \theta_2)}{t} \propto \left(\frac{\theta_1 + \theta_2}{2} - \theta\right)$$

Since w is constant for that body, hence

$$\frac{\theta_1-\theta_2}{t} \propto \left(\frac{\theta_1+\theta_2}{2}-\theta\right)$$

i. e., the rate of fall of temperature is directly proportional to the excess temperature. In fact to verify the Newton's law of cooling this thing is shown to hold true. It can also be written as

$$\frac{d\theta}{dt} \propto \text{excess of temperature}$$

Where $\frac{d\theta}{dt}$ = rate of fall of temperature

$$\frac{d\theta}{dt} = K \text{ excess of temperature} \qquad (K = \text{constant})$$

EXPERIMENT 8·1

Object—Verify Newton's law of cooling by ploting a cooling curve for a liquid.

Apparatus—Newton's law of cooling apparatus (it consists of a double walled vessel with a lid containing a calorimeter with stirrer), two thermometers reading up to $\frac{1}{10}$ °C, stop watch, heater or burner etc.

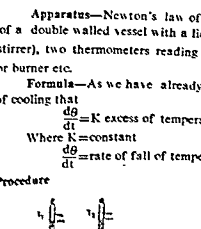
Formula—As we have already obtained from Newton's law of cooling that

$$\frac{d\theta}{dt} = K \text{ excess of temperature}$$

Where K = constant

$$\frac{d\theta}{dt} = \text{rate of fall of temperature}$$

Procedure



1. Heat water in a beaker up to its boiling point.

2. Transfer the boiling water to fill the calorimeter A up to 3/4 of its capacity. Put the calorimeter A in its place in the Newton's law of cooling apparatus as shown in the figure (8·1).

re is thermometer T_1

fitted to record the temperature of cooling water and S is the stirrer.

3. Stir water continuously and take down the temperature of water at the interval of every half minute or one minute.

4. Plot a graph between the temperature and time taking a suitable scale. Temperature and time are taken along the y-axis and the x-axis respectively as shown in the figure 8·2.

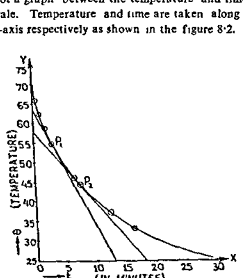


Fig. No. 8·2

5. Draw a number of tangents at the points P_1, P_2 and so on. The tangents at different points gives the rate of fall of temperature corresponding to those points. Determine the excess of temperature at these points.

6. Now plot a graph between this excess of temperature and rate of fall of temperature, i. e., $\frac{d\theta}{dt}$ taking excess of temperature x-axis and $\frac{d\theta}{dt}$ along the y-axis as shown in the

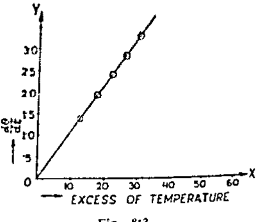


Fig. 8·3

Observations

S. No.	1	2	3	4	5	—	—	—	—
Time	0'	½'	1'	1½'	2'	—	—	—	—
Temperature	0°C	°C	°C	°C	°C				

Table from graph of fig. 8·2.

S.No.	Room temp.	Temp. of cooling water	Excess of temperature	Angle of the slope of tangent	$\frac{d\theta}{dt}=\tan\alpha$
1	.... °C	°C	°C		
2	" °C	°C	°C		
3	" °C	°C	°C		
4	" °C	°C	°C		
5	" °C	°C	°C		
6	" °C	°C	°C		
7	" °C	°C	°C		

Calculations

$\frac{d\theta}{dt}$ is determined from the table of natural tangents. For a particular value of $\frac{d\theta}{dt}$ we measure the angle between the tangent at that point of the curve in figure 8·2 and x-axis.

$$\frac{d\theta}{dt}=\frac{\text{Intercept cut by tangent on y-axis}}{\text{Intercept cut by tangent on x axis}}$$

Result

The graph between $\frac{d\theta}{dt}$ and excess of temperature comes to be a straight line which proves that the rate of cooling is directly proportional to the excess of the temperature.

If we calculate the ratio of $\frac{d\theta}{dt}$ and excess of temperature which gives a constant K this also proves the Newton's law of cooling.

Precautions

1. The water should be stirred constantly.

2. Thermometers should read up to 0·1°C.

3. The curves plotted should be smooth. They should pass through the mean positions and if points are left, they should be on both sides of the curve almost in equal number and almost at the equal distances.

EXPERIMENT 8 2

Object–To determine the specific heat of a liquid by Newton's law of cooling method.

Apparatus–Newton's law cooling apparatus (a double walled vessel containing two identical calorimeters), Two thermometers, stop watch, pippet, balance, weight box, given liquid, burner or heater.

Theory

If two identical calorimeters contain equal volumes of two different liquids, the outer surfaces of the calorimeters are of the

same nature and both are cooled under same conditions, then t rate of cooling are equal.

Suppose two calorimeters of same size contain water liquid and these are cooled from temperature θ_1 to θ_2 du the intervals t_1 and t_2 seconds respectively. Then

Rate of cooling of watet = Rate of cooling of liquid

Rate of cooling of water $= \frac{(m_1+W)(\theta_1-\theta_2)}{t_1}$ calories/s

rate of cooling of the liquid $= \frac{(m_2S+W')(\theta_1-\theta_2)}{t_2}$ calories/sec

$$\therefore \quad \frac{(m_2S+W')(\theta_1-\theta_2)}{t_2} = \frac{(m_1+W)(\theta_1-\theta_2)}{t_1}$$

$$Or\ S = \frac{1}{m_2}\left[\frac{t_2}{t_1}\ (m_1+W) - W'\right]$$

Where S = The specific heat of the liquid

W = Water equivalent of the calorimeter containin water.

W' = Water equivalent of the calorimeter containin liquid.

m_1 = Mass of certain volume of water taken.

m_2 = Mass of equal volume of liquid taken.

Procedure

1. Weigh two identical clean calorimeters separately and calculate their water equivalents (mass × specific heat = water equivalent of a body). Blacken them from outside.

2. Heat water and liquid in two separate beakers in a common bath up to 70°C or 80°C. Transfer equal volume of water and liquid into two identical calorimeters with the help of clean pippets.

3. Put these calorimeters in their positions inside the cooling apparatus as shown in the figure 8.4. Press a thermometer in ... the corks. Stirrers are also provided in

5. With the help of a stop watch note down the temperature of water and liquid alternately after every $\frac{1}{2}$ minute till the temperature fall just 5°C to 10°C above the room temperature.

6. Note down the temperature of surroundings. It is better to note the temperature of surroundings at the beginning of the experiment also and then to find the mean of the two.

7. Weigh the two calorimeters separately with their contents.

8. Plot the cooling curves for water and liquid on the same graph paper taking the suitable scales. Time is taken along the x-axis and temperature along the y-axis.

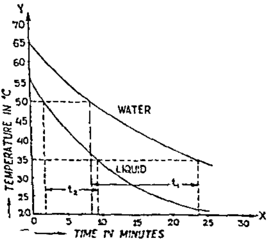


Fig. 8.4

9. From these curves, the time taken by water and liquid in cooling through the same range of temperature is noted.

10. Calculate the specific heat of the liquid using the formula given.

Observations

1. Mass of the first calorimeter = gm
2. Mass of the second calorimeter = gm
3. Mass of the first calorimeter + water = gm
4. Mass of the second calorimeter + liquid = gm
5. Room temperature in the beginning = °C
6. Room temperature at the end of the experiment = °C

S. No	Time, in minutes	Temperature of water	Temperature of liquid
1			
2			
3			
4			
5			
6			

Calculations

Water equivalent of first calorimeter, $W = m s_1$ = gm.

" " second " , $W' = m_1 s_1$ = gm.

(s_1 is the specific heat of the material of calorimeter)

Mass of water = (3 − 1) = gm

Mass of liquid = (4 − 2) = gm

Time taken by water cooling from $\theta_1°$ to $\theta°_2$= minutes

" " " liquid " " = minutes

$$S= \frac{1}{m_2}\left[\frac{t_2}{t_1}(m_1+W)-W1\right]$$

$$= \frac{1}{20{\cdot}10}\left[\frac{7}{10}(25{\cdot}85+10{\cdot}49\times0{\cdot}1)-10{\cdot}26\times0{\cdot}1\right]$$

$$= \frac{1}{20{\cdot}10}\left[\frac{7}{10}\times26{\cdot}90-1{\cdot}026\right]$$

$$= \frac{1}{20{\cdot}10}\left[18{\cdot}83-1{\cdot}026\right]$$

$$= \frac{17{\cdot}80}{20{\cdot}10}$$

$\log 17{\cdot}80=1{\cdot}2504$

$\underline{\log 20{\cdot}10=1{\cdot}3032}$

Diff. $=\bar{1}{\cdot}9472$

$\therefore S=$ Antilog $\bar{1}{\cdot}9472$

$= 0{\cdot}8855$

$= 0{\cdot}89$

Result

Specific heat of a given liquid=
Standard result=
Percentage error=

Precautions—Same as in experiment 8·1

Oral Questions

1. State Newton's law of cooling. What are its limitations?

2. Explain the rate of cooling and how do you measure it?

3. What is radiation? What are the factos governing radiation?

4. Explain the nature of surface pertaining to radiation.

5. Define the terms specific heat and water equivalent.

6. What do you mean by identical calorimeters with respect to radiation?

7. Can you find specific heat of a solid by the method of Newton's law of cooling?

9

COMPOUND MICROSCOPE

Compound microscope—It consists of a brass tube having an objective at one end an eye-piece at another end. The eye-piece can be moved in and out of the microscope tube. Both, the *objective* and *the* eye-piece, are convex lenses or in case of superior instruments combination of the lenses behaving as convex lens where the defects like chromatic and spherical aberrations are eliminated or reduced considerably.

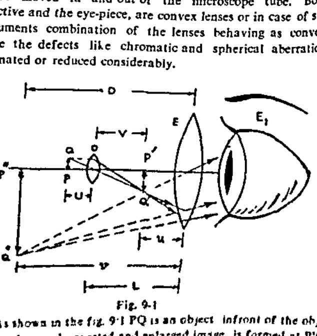


Fig. 9·1

As shown in the *fig.* 9·1 PQ is an object *infront of the* objective O and its real, inverted and enlarged image is formed at $P'Q'$. $P'Q'$ behaves as an object *for the* eye-piece and its virtual, upright and enlarged image is formed at $P''Q''$. The final image is magnified and inverted with respect to the object under observation.

Magnifying power *of a microscope is defined as the ratio of the angle subtended by the image at the eye to the angle subtended by the object at the eye when the object is also at the least distance of distinct vision, D.*

$$\therefore \quad M = \frac{P''Q''/D}{PQ/D}$$

$$= \frac{P''Q''}{PQ}$$

$$= \frac{P''Q''}{P'Q'} \times \frac{P'Q'}{PQ}$$

Therefore $M = \frac{V}{U} \times \frac{v}{u}$ $\left(\text{Because } \frac{I}{O} = \frac{v}{u}\right)$ .... (1)

For a convex lens, we have

$$-\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

Multiplying by v throughout, we get

$$-\frac{v}{f} = \frac{v}{v} - \frac{v}{u}$$

or $\quad \frac{v}{u} = 1 + \frac{v}{f}$ .... (2)

Since $v = D$, $f = f_e$ (for eye-piece), and U is almost equal to the focal length of the objective, i. e., f_o. Therefore (1) becomes

$$M = \frac{V}{f_o}\left(1 + \frac{D}{f_e}\right) \quad .... (3)$$

EXPERIMENT 9·1

Object—To determine the magnifying power of a microscope.

Apparatus—A compound microscope, scale, graph paper etc.

Theory

$$M = \frac{\text{Angle subtended by the image at the eye}}{\text{Angle subtended by the object when it is also at the distance D}}$$

$$= \frac{P''Q''/D}{PQ/D}$$

On a scale if $P''Q'' = N$ divisions

and $PQ = n$ division

Then $\quad M = \frac{N}{n}$

Procedure

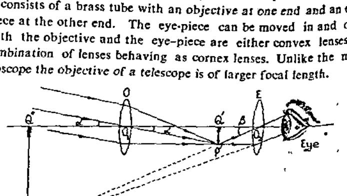
1. Take a graph paper and colour one of the small division with red or blue ink.

10

ASTRONOMICAL TELESCOPE

Astronomical telescope

It is used for observing *heavenly bodies like planets and stars.* It consists of a brass tube with an *objective at one end* and an eye-piece at the other end. The eye-piece can be moved in and out. Both the objective and the eye-piece are either convex lenses or *combination* of lenses behaving as cornex lenses. Unlike the mis-croscope *the objective of a telescope* is of larger focal length.



Fig· 10·1

As shown in the (fig. 10·1) O and E are the objective and the eye-piece coaxially mounted in a brass tube. The parallel beam of rays coming from the distant *object* forms an *inverted, real and diminished image* P′ Q′ *in the focal plane of the objective* O. P′,Q′ behaves as an object for the eye-piece E and its virtual, upright and magnified image is formed at P″ Q′. The final image is inverted with respect to the object under observation.

Magnifying power—*It is defined as the ratio of the angle subtended by the image at the eye to the angle subtended by the object at the eye.* But the object is at such a great distance that the angle subtended by the object at the eye is almost equal to the angle subtended by the object at the *objective.*

According to the (fig. 10·1) β and α are respectively the angle subtended by the image at the eye and the angle subtended by the object at the objective.

$\therefore$ Magnifying Power $= \frac{\angle\beta}{\angle\alpha}$

since β and α are very small angles

$$\therefore M = \frac{\tan\angle\beta}{\tan\angle\alpha}$$

$$= \frac{P'Q'/Q'O_2}{P'Q'/Q'O_1}$$

$$= \frac{Q'O_1}{Q'O_2}$$

$$= \frac{F}{f}$$

Where F and f are the focal lengths of the objective and the eye-piece respectively.

EXPERIMENT 10 1

Object—Determine the magnifying power of a telescope.

Apparatus—A telescope, a scale, measuring tap etc.

Theory—Let P Q be the object and the angle subtended by it at the objective is α. The final image P'' Q'' subtends the angle β at the eye,

$$M = \frac{\angle\beta}{\angle\alpha}$$

As shown in the fig. (10·2) there is a telescope T mounted on a vertical stand and a vertical scale is fixed on a wall at a distance D from the telescope. Some divisions on the scale are observed with the help of the telescope with one eye and at the same time with the help of another eye. It is estimated that how many divisions are covered on the vertical scale by these magnified divisions.

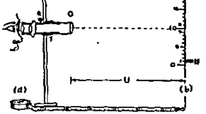


Fig. 10·2

Suppose the number of divisions observed through the telescope are n and the number of divisions covering them when observed directly are N. If d is the span of each division, then

$$\angle\beta = \frac{Nd}{D}$$

and $\angle\alpha = \dfrac{nd}{D}$

Hence $M = \dfrac{N}{n}$

Procedure

1. Place the telescope mounted on a vertical stand at a distance about 5 to 7 metres from a vertical scale fixed on a wall.

2. Adjust the eye-piece such that cross-wires are clearly visible.

3. Now see the scale with one eye through the telescope and concentrate on certain number of divisions, say n. With the other eye see the scale directly and count the number of divisions which coincide with the magnified n divisions. Suppose these are N in number.

4. Repeat the experiment with different number of n divisions.

5. Repeat the experiment with different distances from the scale.

Observations

S. No.	Distance of the scale from the telescope	No. of divisions seen through the telescope n	No. of divisions seen directly N	$M=\frac{N}{n}$
1	315 cm	1	8	8
2	,,	2	14	7
3	,,	3	23	7·6
4	535 cm	1	7	7
5	,,	2	15	7·5
6	,,	3	20	6·6
7	700 cm	1	6	6
8	,,	2	13	6·5
9		3	21	7

Calculations

$$M = \frac{8}{1} = 8$$

Result

Magnifying power of a given telescope =

Precautions

1. The eye should be kept near the eye-piece.

2. The divisions marked on the scale must be clearly visible when seen directly with the naked eye.

Oral Questions

1. What is the construction of astronomical telescope ?

2. What are the different types of telescopes ?

3. Explain the working of an astronomical telescope What is the nature of the image observed ?

4. Define the magnifying power of the telescope.

5. How do you differentiate a telescope from a miscroscope ?

6. Suggest how a telescope of larger magnifying power can be constructed.

11

RESONANCE TUBE

Object—Determine the velocity of sound in air at 0°C by *resonance tube and also determine the end correction* of the resonance tube by finding the first and second resonance lengths.

Apparatus—Resonance tube, vernier callipers, *A rubber pad*, a thermometer, set squares, three tuning forks of frequencies 512,480,427 or any other combination.

Theory—(i) At resonance, i.e. when loud sound is heard, frequency of air column = frequency of tuning fork (n).

(ii) Water level serves as a closed end of the tube and it serves two purposes –

(a) *Reflection of waves takes place at the water* level.

(b) Water level can be raised or lowered to adjust the length of air column to achieve resonance.

(iii) Antinode is formed above the open end at a distance x. If l_1 and l_2 *are the first and second resonance* lengths obtained with a fork of frequency n,

$$l_1 + x = \frac{\lambda}{4}$$

and $$l_2 + x = \frac{3\lambda}{4}$$

(iv) Hence $x = \frac{l_2 - 3l_1}{2}$ (End correction)

(v) The velocity v_t at room temperature $t°C$ *is given* by $V_t = 2n(l_2 - l_1)$

(vi) If V_0 = Velocity of sound at 0°C, then

$$\frac{V_t}{V_0}=\left(\frac{T}{T_0}\right)^{1/2}=\left(\frac{273+t}{273}\right)^{1/2}$$

So that $V_0=V_t\left(\frac{273}{273+t}\right)^{\frac{1}{2}}$

(vii) Also approximately $x = \cdot 3D$, where D is the inner diameter of the resonance tube.

Procedure—

1. Set the resonance tube vertical using a plumb line and the levelling screws at the base of the apparatus. Fill the reservoir and the resonance tube partly with water.

2. Place the thermometer bulb into the mouth of the tube

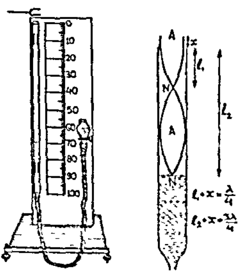


Fig. 11.1

and note the temperature. See that the bulb does not dip into water.

3. Holding the tuning fork by the stem, strike it gently on the rubber pad and place it horizontally just above the open end

of the tube so that the prongs vibrate in the vertical plane and do not touch the edge of the tube.

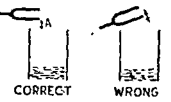


Fig. 11·2

Note:—The end A of the prong of the fork should be at the centre of the mouth of the tube. If the fork is not perfectly horizontal, the waves sent downwards by it will be reflected from the walls of the tube instead of from the water surface.

4. Lower the reservoir and using the pinch cock, adjust the length of air column so that the maximum possible sound is heard. Now resonance has been achieved. Measure the length of air column. This is l_1. Measure l_1 twice, once while lowering the level of water and again while raising the level of water.

5. Further lower the reservoir. Again maximum sound will be heard when length of air column becomes slightly greater than 3 l_1. This is l_2. Measure l_2 twice, once while lowering the level of water and again while raising the level of water above the position obtained.

6. Repeat the experiment with the second and the third tuning forks. Calculate velocity of sound at t°C and 0°C by eqns. *(v) and (vi) respectively.*

7. Calculate the end correction by eqn (iv) and verify it by eqn (vii). Measure the *internal* diameter of the tube with inside callipers in two positions at right angles.

S. No.	Frequency of fork	Upper resonance point: Reading of water level: Falling level	Rising level	Mean l_1	Lower resonance point: Reading of water level: Falling level	Rising level	Mean l_2	l_2-l_1
1.	$n_1=512$ v/s	cm	cm	cm	cm	cm	cm	33·6 cm
2.	$n_2=480$ v/s							
3.	n_3							

V.C. of vernier scale $= \frac{\text{The smallest division on main scale}}{\text{Total number of divisons on V. scale}}$

= ... ... cm

Zero error = ... cm

Zero correction = ... cm

Internal diameter of tube in one direction = ... cm

" " " $\perp$ direction = ... cm

Mean internal diameter of the tube D = ... cm

Calculation for V_0

1. $V_t = 2\times512\times33{\cdot}6$ log 1024=3·0103
$=1024\times33{\cdot}6$ log 33·6=1·5263
$=34410$ cm/sec antilog 4·5366
$=34410$

2. $V_t = 2\times480\times$......
$=$ ... cm/sec

3. $V_t =$ ... cm/sec

Mean $V_t =$

273=2·4362
·3=2·4698
$\bar{1}$·9664

$$\log\left(\frac{271}{3??}\right)^{\frac{1}{2}} = \bar{1}.9932$$

$$\log 343.2 = 2.5341$$

$$\text{Antilog } 2.5211$$

$$V_0 = 332\ \text{metres/sec} \qquad = 332.1$$

Calculations for x (end correction)

S. No.	Freq. of fork	Mean l_1 cm	Mean l_2 cm	$3l_1$ cm	$l_2 - 3l_1$ cm	$x = \frac{l_2 - 3l_1}{2}$ cm	Mean x cm	$\cdot 3D$ cm
1.								
2.								
3.								

Result

Velocity of sound at 0 C (by Experiment) = ... Metres/sec

Standard result	= 332·0 Metres/sec	
Error	=	
Percentage Error	=	%
End correction x	=	cm
·3D	=	cm
Difference	=	cm

Precautions

1. The resonance tube should be set vertical using levelling screws.

2. A pinch cock should be used and when the pinch cock is closed, water level should not change.

3. Temperature of air in the tube should be measured and not the temperature of water.

4. The inner diameter of the tube should be determined in two mutually perpendicular directions.

5. The tuning fork should be held only from its stem so that ... frequency may not get affected.

6. The vibrating fork should be held perfectly horizontal, just above the open end of the tube and without touching the edge of the tube. The end of the prong has got maximum amplitude of vibration, so the end should be at the centre of the mouth of the tube.

7. The resonance should be obtained both for water level falling and rising in the tube, while determining l_1 or l_2. The water level should be raised or lowered in small steps lest the resonance position should get missed.

8. Tuning forks of high frequencies e.g. 512, 480, etc. should be used. With forks of low frequencies, the second position of resonance is not obtained because l_2 in their case would become larger than the whole length of the resonance tube.

9. The tuning fork should be kept vibrating all the time when the water level is made to rise or fall for determining the correct position of maximum loudness.

Modifications

EXPERIMENT 11·2

Object—Find the frequency of a given fork using resonance tube, given the velocity of sound at 0°C 332 meters/sec.

Hint : First Calculate $V_t = V_0 \left(\frac{273+t}{273}\right)^{\frac{1}{2}}$ where t is the room temperature

Then using the equn. $V_t = 2n\,(l_2 - l_1)$

$$n = \frac{V_t}{2(l_2 - l_1)}$$

So n can be calculated by determining l_1 and l_2 experimentally.

EXPERIMENT 11·3

Object—Compare the frequencies of the two given tuning forks by using resonance tube.

Hint: $V_t = 2n_1\,(l_2 - l_1) = 2n_2\,(l_2' - l_1')$

$$\therefore \frac{n_1}{n_2} = \frac{l_2' - l_1'}{l_2 - l_1}$$

So by finding the first and second resonance lengths with both the forks, the ratio of their frequencies can be calculated.

EXPERIMENT 11·4

Object – Determine the temperature coefficient of the velocity of sound using resonance tube. Given velocity of sound at 0°C 332 metres/sec.

Hint $V_t = V_o + \alpha t$ where α is the *temperature coefficient.*

so $\alpha = \dfrac{V_t - V_o}{t}$

V_o is given and V_t can be determined experimentally, using *the formula* $V_t = 2n(l_2 - l_1)$

Oral Questions

1. Why the tube is called resonance tube ? What is resonance and what is end correction ?

2. *Do you find the velocity of sound in air, or in water or in the material of the tuning fork ?*

3. Why is water used ? Will the velocity of sound be affected if instead of water, oil or mercury is used in the tube ?

4. When first and second resonance lengths are obtained, are the frequencies of the air column in both the cases, the same ? *Are they equal to the frequency of fork in both the cases ?*

5. Are the fundamental frequencies the same when first and second resonance lengths are obtained.

6. Can you obtain the third resonance length also ? If so, how many times will it be l_1 ?

7. *If the room temperature increases, will the values of* l_1 *or* l_2 *also increase or decrease or remain the same ?*

8. *What kind of waves are present in the tube-progressive or stationary ? Are they longitudinal or transverse waves ?*

9. *When the fork vibrates, what type of vibrations are these ?*

10. *How do you select the tuning fork for this experiment ? Should it be of high frequency or low frequency ? and why ?*

11. Can this method be *used to find* the frequency of a fork ? If so, which method is better *for the* determination of frequency ... Sonometer method ?

12

SONOMETER

Object—Determine the frequency of a given tuning fork with the help of a sonometer.

Apparatus—Sonometer with a wire stretched on it, a hanger with slotted half-kilo weights, a tuning fork, a striking pad of rubber, a light V shaped paper rider, a metre rod.

Theory—Transverse stationary waves are produced in the stretched string by pressing the stem of the vibrating fork against the surface of the sonometer board. Then length of the vibrating wire between the bridges is adjusted till frequency of vibration of wire becomes equal to that of fork. So resonance occurs and therefore amplitude of vibration of the string becomes very large at the antinodes. So a paper rider placed at the position of the antinode falls off the wire.

$$n = \frac{1}{2l}\sqrt{\frac{T}{m}}$$

Where n = the frequency of length l of the wire.

= the frequency of fork, at resonance.

l = length of the wire between the bridges in cms measured on achieving resonance.

T = the tension in dynes under which the wire is stretched.

T = Mg dynes where M is the weight in gms, of the hanger and the half kilo weight placed on the hanger.

m = mass per unit length of the wire

= volume per unit length of the wire $\times$ density.

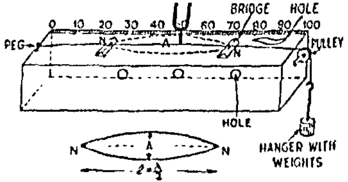
m = $\pi r^2 \rho$ where r is the radius of the wire and ρ is the density.

$$\therefore \qquad n = \frac{1}{2l}\sqrt{\frac{T}{\pi r^2 \rho}}$$

$$n = \frac{1}{2lr}\sqrt{\frac{T}{\pi \rho}} \text{ But } 2r = D \text{, the diameter.}$$

$$\therefore \qquad n = \frac{1}{lD}\sqrt{\frac{T}{\pi \rho}}$$

Knowing D, T, and ρ, and determining resonant length l, frequency n, can be calculated.



wire increases. The stem of the vibrating fork is to be kept pressed against the sonometer board all the time. For a particular length l of the wire between the bridges, the paper rider is thrown off the wire. It means now frequency of the wire has become equal to the frequency of the fork, so resonance has been achieved, as a result of which the amplitude of vibration at the antinode (middle of the wire) has become large and consequently the paper rider has been thrown off the wire. *Now place a metre rod edge wise, along the wire and read the positions of the bridges, on this metre rod.* So find the resonant length of the wire between the bridges.

5. Again find the resonant length of the wire, stretched under the same tension and with the same fork, but this time, the resonant length is to be obtained while decreasing the distance between the bridges.

6. Find the mean of the resonant lengths obtained in (4) and (5), for the same tension. Next change the tension in steps of 1 kgm each and every time find the mean of the resonant lengths obtained while first increasing the distance between the bridges and then while decreasing the distance between the bridges.

7. Then calculate, corresponding to every tension employed the frequency of the fork using the formula

$$n = \frac{1}{lD}\sqrt{\frac{T}{\pi\rho}}$$

Then find the mean value of n.

Note:– 1. *While recording the tension T, in the observation table, remember that weight of the hanger has been added to the weights, placed on the hanger, for the purpose of calculating T.*

2. *To read the resonant length of the wire, it would be advisable not to use the metre rod provided on the board. For accurate measurement, a metre rod may be placed edge wise along the wire and the positions of the two bridges may be noted on this metre rod.*

Observations

(a) Determination of diameter.

Mean diameter = $\frac{\text{......}}{6}$ = ... cm

Corrected diameter D = 1·14 cm (say)

(b) Determination of resonant length

S. No.	Weight plus weight of hanger	Distance increasing: Position of first bridge cm	Distance increasing: Position of second bridge cm	Distance increasing: Resonant length l' (cm)	Distance decreasing: Position of first bridge cm	Distance decreasing: Position of second bridge cm	Distance decreasing: Resonant length l'' (cm)	Mean resonant length $l = \frac{l'+l''}{2}$ (cm)
1.	1·5 kgm							
2.	2·0 kgm	...	...	...	...	...	...	25·1 cm
3.	2·5 kgm							...

Material of the wire = Steel (say)

So density of the material of the wire = 7·8 gm per cc (for steel)

(from tables)

Calculations

1.

2. $n = \frac{1}{lD}\sqrt{\frac{T}{\pi\rho}}$

$n = \frac{1}{25 \cdot 1 \times \cdot 046} \cdot \left(\frac{2000 \times 980}{3 \cdot 142 \times 7 \cdot 8}\right)^{1/2}$

$n = \frac{1}{25 \cdot 1 \times \cdot 046} \times (x)^{1/2}$

Where $x = \frac{2000 \times 980}{3 \cdot 142 \times 7 \cdot 8}$

So $n = 244 \cdot 8$ vibs/sec.

$\log 2000 = 3 \cdot 3010$

$\log 980 = 2 \cdot 9912$

Add $\overline{6 \cdot 2922}$ (1)

$\log 3 \cdot 142 = 0 \cdot 4972$

$\log 7 \cdot 8 = 0 \cdot 8921$

Add $\overline{1 \cdot 3893}$ (2)

(1)—(2) $= 4 \cdot 9029$

i. e. $\log x = 4 \cdot 9029$

and $\log x^{\frac{1}{2}} = \frac{4 \cdot 9029}{2}$

$= 2 \cdot 4514$

$\log 25 \cdot 1 = 1 \cdot 3997$

$\log \cdot 046 = \bar{2} \cdot 6628$

Add $\overline{0 \cdot 0625}$ (

(3)—(4) $= 2 \cdot 3889$

antilog $2 \cdot 3889 = 244 \cdot 8$

3.

4.

Result

Mean n = vibs/sec.

Standard result = vibs/sec.

Error = ... vibs/sec.

% error =

Precautions

1. The wire should be uniform in diameter, free fro[m] [k]inks.

2. Start with a small length of the wire between the bridge[s] [a]nd adjust it for unison by gradually increasing the length. Thi[s] [l]ength should be checked by finding the resonant length agai[n] [w]hen the distance between the bridges is decreased.

3. Weight of the hanger must be included while calculating [th]e tension.

4. The hanger should not be moving when resonant length is [b]eing determined.

5. The friction in the pulley should be the minimum possible, [a]lmost negligible.

6. The paper rider must always be kept at the middle of the [w]ire (i.e. at the position of the antinode), between the bridges.

7. Use a fork of smaller frequency. This would increase the accuracy by increasing the resonant length.

8. With large tension used, the resonant length will increase so the accuracy also increases. But tension applied must be within the elastic limit of the material of the wire.

Criticism of the method

There are many sources of error in the experiment.

1. The sonometer wire is not perfectly flexible. Due to its stiffness its *frequency is greater if it were perfectly flexible.*

2. *The frequency of vibration of the wire may change due to* the yielding of the supports, because yielding would then result in shifting the positions of nodes *from the bridges.*

3. The tension on both the sides of the bridge may not be the same.

4. The friction in the pully causes T to be less than that actually applied. So the calculated *frequency* is more than the *actual frequency.*

Oral Questions

1. Define resonance, stationary waves, fundamental frequency and harmonics. What is sharp resonance and what is flat resonance ?

2. *Which method is better for determining the frequency of* a fork—sonometer method or resonance tube method ?

3. *What type* of vibrations are produced in a *tuning fork ?* Where are the nodes and *antinodes situated in a vibrating fork ?* On what factors does the frequency of a fork depends ? What is the purpose of the stem ? Of what materials the forks are made ? Why are forks of *frequencies 100, 200, ...not chosen for laboratory* use ?

4. Why is *it better to* have a thinner wire of lower Young's modulus and to stretch it with a *large load ? Is it necessary to* stretch the wire horizontally ? Which is better, *horizontal* or vertical *arrangement ?* Can a rubber cord be used. Explain the principle of working in this *experiment.* What type of vibrations are produced in the string.

5. What is the function of the sounding board and of the bridges ? Why the edges of the bridges should be sharp ? Why is the box hollow and why holes are provided in it ?

6. Explain the principle of the rider. Why should the rider be always kept at the middle of the wire between the bridges ?

7. What are the sources of error in the experiment and what precautions are to be observed ? What is the use of the sonometer?

8 On what factors does the frequency of a note emitted by a sonometer wire depend ? How will the frequency change—

(i) if the tension is made four times ?

(ii) if the area of cross-section of the wire increases four times ?

(iii) if the radius of the wire increases four times, provided other factors remain the same in each case ?

EXPERIMENT 12·2

Object—Verify the laws of transverse vibrations of strings.

(A) Verification of the law of length.

Apparatus—Sonometer, hanger with weights, striking pad, paper rider, tuning forks of different frequencies say 256, 288, 320, 341, 384 etc. A metre rod to measure the resonant lengths.

Theory

When T and m are constt

$$n \propto \frac{1}{l} \text{ or } n\,l = \text{constant}$$

Where T = the tension under which the wire is stretched.

m = the mass per unit length of the wire.

n = the frequency of vibration of length 1 cm of the wire.

Procedure

1. Place suitable weights on the hanger so that the wire is stretched (use a load of 2·0 or 2·5 kgm).

2. Place a V—Shaped paper rider at the middle of the wire between the bridges.

3. Take the first fork of frequency n_1. Strike it against a rubber pad and press the stem of the vibrating against the sonometer board, simultaneously adjusting the of the wire between the bridges till for a particular length, paper rider is thrown off the wire. Find this resonant twice, first while increasing the distance between the bridges then while creasing the distance between the bridges. Find mean resonant length l_1.

4. Repeat the process with other tuning forks of frequen n_2, n_3,.... and find the mean resonant lengths l_2, l_3.... respective The tension is to be kept the same in all these observations and wire is also not to be changed.

5. Calculate the products $n_1\ l_1$, $n_2\ l_2$, $n_3\ l_3$... etc. These woul come out to be constant.

6. Draw a graph between n and $\frac{1}{l}$. It will be found to be straight line passing through the origion.

Observations

Load including the hanger = 2 kgm (kept constant)

S. No.	Frequency of the fork (n)	Resonant length obtained by increasing the distance between the bridges	Resonant length obtained by decreasing the distance between the bridges	Mean resonant length (l)	from reciprocal tables $\left(\frac{1}{l}\right)$	nl
1.	256 v/s					
2.	288 v/s					
3.	320 v/s					
4.	341 v/s					

Calculations

Result

1. The product n l comes out to be constt.

i.e., n l = constt.

2. The graph between n and $\frac{1}{l}$ comes out to be a st. line. It also means that $n \propto \frac{1}{l}$, i.e., the frequency of vibration of a given wire (m = constt.) stretched under constant tension (T = constt.) is inversely proportional to its length. This is the law of length, which is verified.

(B) The law of tension.

Apparatus—Sonometer with a wire stretched over it, hanger with weights, striking (rubber) pad, paper rider, a metre rod to measure the resonant lengths, one fork of a particular frequency, say 256.

Theory

When l and m are constt.

$$n \propto \sqrt{T}$$

When n = the frequency of fixed length l of the given wire

T = the tension in dynes under which the wire is stretched.

Procedure

1. Take one fork only, of frequency, n_1 (say). Start with 1 kgm load and under this tension T_1, find the mean resonant length l_1 in unison with the fork.

2. Increase the tension in steps of $\frac{1}{2}$ kgm, three or four times and thus find the resonant lengths l_2, l_3, l_4 under tension T_2, T_3, T_4 respectively, of the same wire and in unison with the same fork of frequency n_1. Then

$$n_1 = \frac{1}{2l_1}\sqrt{\frac{T_1}{m}} = \frac{1}{2l_2}\sqrt{\frac{T_2}{m}} = \frac{1}{2l_3}\sqrt{\frac{T_3}{m}} = \frac{1}{2l_4}\sqrt{\frac{T_4}{m}}$$

In second case, when the tension is T_2, if lengths were l_1 insted of l_2, the frequency would have been n_2 (say) instead of n_1. Using law of length,

$$n_2 l_1 = n_1 l_2$$

$$\text{i.e.} \quad \boxed{n_2 = n_1 \times \frac{l_2}{l_1}}$$

$$\frac{n_2}{\sqrt{T_2}} = \frac{295 \cdot 9}{38 \cdot 73} = 7 \cdot 640$$

log 295·9 = 2·4711
log 38·73 = 1·5880
antilog $\overline{0·8831}$
= 7·640

$$\frac{n_3}{\sqrt{T_3}} = \frac{337 \cdot 2}{45 \cdot 19} = 7 \cdot 541$$

log 337·2 = 2·5279
log 45·19 = 1·6505
antilog $\overline{0·8774}$
= 7·541

Result

Values of $\frac{n}{\sqrt{T}}$ are found to be constt.

So $\frac{n}{\sqrt{T}}$ = constt. or $n \propto \sqrt{T}$

Also graph between $n \propto \sqrt{T}$ comes out to be a straight line. It also means $n \propto \sqrt{T}$, i.e., frequency of fixed length (l = constt.) of a given wire (m = constt.) is directly proportional to the square root of the tension under which the wire is stretched. This is the law of tension and it stands verified.

(c) Verification of the Law of Mass

Apparatus—Sonometer, hanger with slotted weights, a striking pad of rubber, a tuning fork of particular frequency (say) 256, a metre rod, three wires having different masses per unit length by virtue of their different materials or different diameters.

Theory

$$n \propto \frac{1}{\sqrt{m}} \text{ when } T \text{ and } l \text{ are constt.}$$

where n is the frequency of vibration of fixed length l of the wire, whose mass per unit length is m.

T = the tension under which the wire is stretched.

Procedure

1. Stretch the first wire with a suitable load say T = 2kgm and find its mean resonant length l_1 which is in unison with a particular fork of frequency n_1. The ... of this wire is m_1.

2. Replace the first wire with the second one, whose mass per unit length is m_2. Find its length l_2, under the same tension $T=2$ kgm and in unison with the same fork of frequency n_1. Similarly find the length l_3 of the third wire (mass per unit length $=m_3$), under the same tension $T=2$ kgm and in unison with the same fork of frequency n_1.

$$\text{Then } n_1=\frac{1}{2l_1}\sqrt{\frac{T}{m_1}}=\frac{1}{2l_2}\sqrt{\frac{T}{m_2}}=\frac{1}{2l_3}\sqrt{\frac{T}{m_3}}$$

length l_2 of 2nd wire has got frequency $=n_1$

its length l_1, under the same tension, T, would have

frequency $=n_2$ (say)

Then applying law of length, $n_2l_1=n_1l_2$

$$\text{or } n_2=n_1\frac{l_2}{l_1}$$

$$\text{Similarly } n_3=n_1\frac{l_3}{l_2}$$

For n_1, substitute the frequency of the fork used. So n_2, n_3 are the frequencies of 2nd wire and 3rd wire respectively, calculated for fixed length l_1.

3. Next measure the radii of the wires used and knowing the densities of their materials, calculate the mass per unit length of each wire, using the formula

$$m=\pi r^2\rho$$

Then calculate the products $n_1\sqrt{m_1}$, $n_2\sqrt{m_2}$, and $n_3\sqrt{m_3}$

These are found to be constant.

4. Graph between n and $\frac{1}{\sqrt{m}}$ will be a straight line.

Observations

Pitch of the screw guage = cm

L. C. of the screw guage = cm

Measurement of diameters of the wires.

Wire	Density of Wire in gm/cc (ρ)	Diameter in cms 1	2	3	4	5	6	7	8	9	10	Mean diameter in cm (D)	Radius $r = \frac{D}{2}$	mass per unit length $m = \pi r^2 \rho$
A		...	...	...	...	...	...	...	...	...	...			$m_1 =$ gm/cm
B														$m_2 =$ gm/cm
C														$m_3 =$

Measurement of resonant lengths of the wire
Load including the hanger = 2 kgm (kept constt.)
Frequency of the fork used $= n_1 = 256$ vibrations/sec.
(kept constt.)

Wire	m in gm/cm	$\sqrt{m}$	$\frac{1}{\sqrt{m}}$	Resonant length with frequency n_1 increasing length	Resonant length with frequency n_1 Decreasing length	Mean resonant length (l)	frequency calculated for length l_1 (n)	$n\sqrt{m}$
A	m_1					$l_1 =$ ...cm	$n_1 =$	
B	m_2					$l_2 =$ ...cm	$n_2 = n_1 \times \frac{l_2}{l_1} =$	
C	m_3					$l_3 =$ ...cm	$n_3 = n_1 \times \frac{l_3}{l_1} =$	

Calculations

Result

The values of the product $n\sqrt{m}$ have been found to be constant. It means $n\sqrt{m} =$ constt.

$$Or \quad n \propto \frac{1}{\sqrt{m}}$$

Also a graph between n and $\frac{1}{\sqrt{m}}$ comes out to be a straight line. It also shows that $n \propto \frac{1}{\sqrt{m}}$, i.e., the frequency of vibration

of fixed length of a wire stretched under constant tension is inversely proportional to the square root of the mass per unit length of the wire.

Modifications

EXPERIMENT 12.3

Object—Determine the weight of the given brick. Given forks of different frequencies say 256, 288, 320 and 341.

Hint:— $n=\frac{1}{2l}\sqrt{\frac{T}{m}}$ ...(1)

Where $T=Mg=$ the weight of the brick suspended

So $n=\frac{1}{2l}\sqrt{\frac{Mg}{m}}$

Squaring $n^2=\frac{1}{4l^2}\times\frac{Mg}{m}$

or $Mg=4n^2l^2m$ ...(2)

With the tension due to the same brick, find the resonant lengths l_1, l_2, l_3, l_4 with forks of frequencies n_1, n_2, n_3 and n_4. Calculate m, the mass per unit length of the wire using the formula $m=\pi r^2\rho$ where r is the radius of the wire and ρ is the density of the material of the wire. Knowing n, l and m, find weight Mg of the brick, using relation.

EXPERIMENT 12·4

Object—Determine the density of the material of the sonometer wire. Given a fork of known frequency.

Hint :— $n=\frac{1}{2l}\sqrt{\frac{T}{m}}$ ...(1)

$m=\pi r^2\rho$

$\therefore$ $n=\frac{1}{2l}\sqrt{\frac{T}{\pi r^2\rho}}$

or $n=\frac{1}{2lr}\sqrt{\frac{T}{\pi\rho}}$

or $n=\frac{1}{lD}\sqrt{\frac{T}{\pi\rho}}$

Squaring $n^2 = \frac{1}{l^2 D^2} \cdot \frac{T}{\pi \rho}$

or $\rho = \frac{T}{l^2 D^2 \pi n^2}$ ...(2)

Where $T = Mg$ dynes, Mg being the total load including that of the hanger. (M is in gms.)

n = the frequency of the given fork used.

D = Diameter of the sonometer wire in cms.

l = resonance length of the wire in cms.

Resonant lengths at different tensions and for the same fork, are found out and then formula (2) used to determine ρ.

EXPERIMENT 12.5

Object— Find the diameter of the sonometer wire and verify *your result by measuring the diameter with screw ugage.*

Hint : See Modification (2) above.

From Equation (2), $D^2 = \frac{T}{\pi l^2 n^2 \rho}$

or $D = \frac{1}{nl} \sqrt{\frac{T}{a\rho}}$

Knowing n, l, T, ρ, diameter D can be found out. For different sets, change the tension T and find the resonant length l every time for the same fork.

EXPERIMENT 12.6

Object—**Prove that $\frac{T}{l^2}$ = Constant, l being the length of the sonometer wire, always in unision with the same fork.**

Hint :— $n = \frac{1}{2l} \sqrt{\frac{T}{m}}$

Squaring $n^2 = \frac{1}{4l^2} \times \frac{T}{m}$

or $\frac{T}{l^2} = 4\, n^2 m$ = constt. since n is constant if same fork is used and m is constant if wire is not changed. So find resonant lengths l_1, l_2, l_3 or tensions T_1, T_2, and T_3 in unison

Show that $\frac{T}{l_1^2}=\frac{T_2}{l_2^2}=\frac{T_3}{l_3^2}=$ constt.

Also a graph between T and l^2 will be a straight line.

EXPERIMENT 12.7

Object—Compare the frequencies of two given tuning forks. Take at least three sets by taking three values of tension.

Hint :— $n_1=\frac{1}{2l_1}\sqrt{\frac{T}{m}}$ and $n_2=\frac{1}{2l_2}\sqrt{\frac{T}{m}}$

Dividing $\boxed{\frac{n_1}{n_2}=\frac{l_2}{l_1}}$; $\frac{n_1}{n_2}$ has got no units it being a ratio.

13

DEFLECTION MAGNETOMETER

EXPERIMENT 13.1

Object—Compare the magnetic moments of two magnets by setting the deflection magnetometer in Tan A position and using equal distance method (i.e. deflection method).

Apparatus- Deflection magnetometer, two given magnets, a metre rod.

Theory

When a magnetic needle is placed under the action of two perpendicular fields F and H, then in equilibrium the magnetic needle makes $\angle\theta$ with one of them, say H, such that F = H tan θ (tangent law).

Let M_1 and M_2 be the magnetic moments of the two magnets whose half lengths are l_1 & l_2 respectively. F_1 and F_2 are the fields acting on the compass needle due to these magnets when they are successively placed at a distance d from the pivot of the compass needle, the position of the needle being end on with respect to the magnets θ_1 and θ_2 are the mean deflections obtained in the needle due to the two magnets

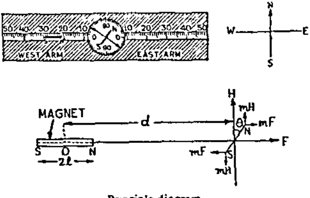
Then (i) $F_1 = \frac{2 M_1 d}{(d^2 - l_1^2)^2} = H \tan \theta_1$

(ii) $F_2 = \frac{2 M_2 d}{(d^2 - l_2^2)^2} = H \tan \theta_2$

(iii) $\frac{M_1}{M_2} = \frac{(d^2 - l_1^2)^2}{(d^2 - l_2^2)^2} \times \frac{\tan \theta_1}{\tan \theta_2}$

(iv) $\frac{M_1}{M_2} = \frac{\tan \theta_1}{\tan \theta_2}$ if $l_1 = l_2$ or the half lengths l_1 & l_2 of

the magnets are so small that l_1 & l_2^2 are negligible compared with d^2.



Principle diagram
Fig. 13·1

Note—1. In the principle diagram magnetic needle should be shown quite small in length compared with the magnet because only then fields acting on its poles can be taken as approximately equal to F, which is actually the field due to the magnet acting at the centre of the magnetic needle.

2. The angle made by the magnetic needle with the field H should be marked as θ.

Procedure

1. First examine the apparatus given to you. See that the aluminium pointer is perpendicular to the magnetic needle and that the needle can rotate freely about its pivot. See that the magnets are not demagnetised and that their poles are correctly marked.

2. **Setting the magnetometer in Tan A position.** Remove all magnets and magnetic substances and any conductors carrying electric current away from the apparatus. Place the magnetometer

with its arms along the East-West direction. To do so corre place a metre rod (its edge should be perfectly straight) on top of the box and parallel to the metre rod fixed on arms of the magnetometer. Then hold the magnetometer fi the extreme ends of the arms and rotate it so that the alumini pointer becomes parallel to the metre rod. This process may ha to be repeated a number of times till, on looking from above dov wards into the plane mirror of the box, it is found that all t three, (i) the aluminium pointer (ii) the metre rod placed on t top of the box, (iii) the metre rod fixed on the arms of the magn tometer, have become parallel among themselves.

Now rotate the compass box so that both the ends of th pointer read zero. Now the magnetometer is set in Tan A positio

3. Now place the magnet A on the East arm with its Nort pole pointing towards the needle. The magnetic axis of the magne should be parallel to the metre rod fixed on the arm, i.e., it should be parallel to the arm and if the magnetic axis is produced, it should pass through the centre of the compass needle pivoted in the compass box. Distance of the magnet from the magnetic needle means the distance from the centre of the magnet to the centre of the magnetic needle. If distance of the end of the magnet from the magnetic needle is read, then to this distance, half the length of the magnet may be added to know the exact distance from the centre of the magnet to the centre of the needle. Adjust this distance so that the deflection is about 40°. Read both the ends of the pointer by keeping your eye vertically above the pointer so that the image of the pointer in the mirror below is covered by he pointer itself.

4. Now reverse the magnet pole to pole on the same arm so hat South pole of the magnet points towards the needle. Keeping he mid. point of the magnet at same distance, read both ends of he pointer. This makes four readings.

5. Reverse the face of the magnet in the same very position id without changing the poles. Read both the ends of the pointer. his makes six readings.

6. Again reverse the poles having the same face above as in (5) and read both the ends of the pointer. This makes eight readings.

7. Now transfer the same magnet on the other arm, i.e., West arm and keeping the mid. point of the magnet at the same distance as on the East arm, repeat the above procedure and take eight readings. This makes sixteen readings for the same magnet A placed at the same distance d, for both the arms of the magnetometer. The mean θ_1 of these sixteen deflections gives the correct value of deflection.

8. Now remove the magnet A away from the apparatus. Place the magnet B in the same way and with its centre at the same distance and repeat the same procedure to note the sixteen deflections. Take the mean of these sixteen deflections. This is θ_2. This forms one set of observation.

9. For the second set and the third set, change the distance and adjust it such that now the magnet A gives a deflection of 45° and 50° respectively in the second set and the third set, whereas it had given a deflection of 40° in the first set.

Note—For the various sets, the distance should be either increased only or decreased only so that the deflections are recorded in same systematic order either in the decreasing order or in the increasing order. Also for various sets, changes in the distance should be uniform, so that uniform changes in the deflection of one magnet are obtained.

10. Calculate $\frac{M_1}{M_2}$ separately for each set and find the mean.

Observations

Length of magnet A = L cm., $l_1 = \frac{5}{12}$ L ......cm.

Length of magnet B = L cm., $l_2 = \frac{5}{12}$ L......cm.

Since the pointer is permanently attached at right angles to the magnetic needle, therefore

deflection of the pointer = deflection of the magnetic needle

Magnet	Dist. of centre of the magnet (d) in cm	Deflection of the pointer in degrees when the magnet is on the East Arm: Face A up: N—pole towards needle		S-pole towards needle		Face B up: N—pole towards needle		S—pole towards needle		West Arm: Face A up: N—pole towards needle		S—pole towards needle		Face B up.: N—pole towards needle		S—pole towards needle		Mean deflection (θ)
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
A	25 cm																	48°
B	25 cm																	47°
A																		
B																		
A																		
B																		

Calculations

$$\frac{M_1}{M_2} = \frac{\tan\theta_1}{\tan\theta_2}$$

$$= \frac{\tan 48^\circ}{\tan 47^\circ} \left(\begin{array}{c}\text{use natural tangents}\\ \text{tables}\end{array}\right)$$

$$= \frac{1{\cdot}1106}{1{\cdot}0724} \qquad \log 1{\cdot}1106 = 0{\cdot}0453$$

$$\underline{\log 1{\cdot}0724 = 0{\cdot}0302}$$

$$\frac{M_1}{M_2} = 1{\cdot}035 \qquad \text{Antilog } = 0{\cdot}0151$$

$$= 1{\cdot}035$$

Result

Mean $\frac{M_1}{M_2}$ = ...(Being a ratio, it has no units).

Precautions

1. The magnetometer should be placed on a rigid table preferably of stone so that it is not shaky and can not be disturbed by other experimenters working on other apparatus. Once set in the desired position, mark its boundary with a piece of chalk and do not hereafter disturb it during the experiment.

2. All magnetic substances and current carrying conductors should be removed away from the magnetometer before setting it and also these should be kept away, during the course of the experiment.

3. Do not measure the dimensions, e.g., length, breadth, etc. of the magnet during the experiment. The contact of vernier callipers, (being of steel) may change the magnetic moment of the magnet.

4. The magnet should be placed on the arms of the magnetometer such that its magnetic axis when produced, must pass through the centre of the magnetic needle.

5. The magnets should be labelled as A and B with ink. Also mark their mid-points and always measure the distances from the mid points of the magnets and NOT from their ends.

6. Tap the top of the compass box, with your finger gently and every time before taking a reading.

7. While reading the position of the pointer on the circular scale, the eye should be vertically above the pointer and in such a

position that the pointer covers its image in the pla *otherwise an error will be made in noting the defle* *deflection can be read correctly if you remember that* *increase from the side of zero and not from the side o*

8. *The distance should be so adjusted that the d* *near about 45°, preferably the deflections obtained for a* *magnet in the three sets should be nearly 40°, 45°, 5* *reading should be 45° and the other two should be equa* *on either side of 45°.*

9. *Distance d should remain the same, for one set* *vation, for both the magnets. Also d should be quite larg* *the field due to the magnet, acting on the magnetic needle* *more uniform.*

Sources of error and their removal

1. The needle or the pointer may not be pivoted ex the centre of the circular scale. One end reads less and th more, than the actual deflection. Hence read both the end pointer and take the mean.

2. The poles of the magnet may not be symmetrically s from the ends. So to eliminate the error on this account, the magnet from pole to pole and read both the ends of the p again.

3. The geometric axis and the magnetic axis of the m may not coincide. Hence the face of the magnet is reverse the above readings repeated.

4. *Zero of the metre-rod may not be coincident with* *centre of the circular scale, i.e., where the needle is pivoted. So* *readings are repeated on the other arm, with the magnet place* *similar position and at the same distance.*

Criticisms of the method

1. The *field* $F = \frac{2Md}{(d^2-l^2)^2}$ due to the magnet acts only at point, i.e., centre of the magnetic needle. The *field acting on t* North pole or the South pole can't be equal to *F*, *the field at t* centre, an assumption which *we make in deriving the formul*

$F=\frac{2\,Md}{(d^2-l^2)^2}=H\tan\theta$. The needle being not a point needle, therefore does not rotate in an absolutely uniform magnetic field.

2. The main defect is that the distance 2l between the poles of the magnet can not be measured accurately.

3. The needle being pivoted and also because it carries a long pointer, some frictional resistance does act against its movement.

4. The system of measuriug deflection by reading the deflection of the pointer over a circular scale is also not very accurate. The accuracy in measuring deflection can be increased by fixing a plane mirror vertically at the centre of the needle and than measuring the deflection by lampe and scale arrangement. Kew magnetometer is more accurate and therefore should be used in place of ordinary deflection magnetometer.

Oral Questions

1. Why the instrument is called a deflection magnetometer? Which one is the needle-the shorter one or the longer one? Why the needle is enclosed in a box? Why must there be two, a needle and a pointer? Could not the circular scale be made of a smaller diameter or the needle made sufficiently long so that the needle itself could serve for the pointer as well?

2. What are the requirements of an ideal pointer? Can you suggest one?

3. Why is the needle deflected when the magnet is placed on the arm of the magnetometer? Why the magnet should be placed parallel to the arms in this setting? What is the harm if the magnet is placed $\perp$ to the arms?

4. Why is the plane mirror fixed below the needle? What are the sources of error in this experiment and how you proceed to remove them?

5. Way the dial of the compass box is levelled? What is the harm if it is not levelled.

6. What will be the nature of the graph, drawn between $\frac{(d^2-l^2)^2}{2d}$ and $\cot\theta$?

Ans. It will be a straight line because

$$F = \frac{2Md}{(d^2-l^2)^2} = H \tan\theta.$$

i.e. $\frac{M}{H \tan\theta} = \frac{(d^2-l^2)^2}{2d}$

$\frac{M}{H} = k$, a const. and $\frac{1}{\tan\theta} = \cot\theta$

$\therefore \quad \frac{(d^2-l^2)^2}{2d} = k.\cot\theta.$

i.e. $\frac{(d^2-l^2)^2}{2d} \propto \cot\theta.$

So a graph between $\frac{(d^2-l^2)^2}{2d}$ and $\cot\theta$ will be a straight line. Remember that $\cot\theta = \tan(90-\theta)$, i.e., if you want to find the value of cot 38°, then subtract 38 from 90°. It gives you 52°. Then tan of 52° will be the same as cot of 38°.

EXPERIMENT 13.2

Object—Compare the magnetic moments of two magnets setting the deflection magnetometer in Tan-B position and using Equal distance method.

Theory

(i) $F = H\tan\theta$ (tangent law)

Where F and H are the two perpendicular fields acting simultaneously on the magnetic needle. $\angle\theta$ is the $\angle$ made by the magnetic needle with the field H, when it comes into equilibrium.

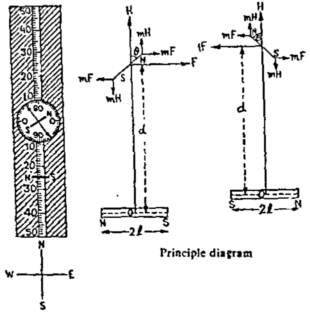
(ii) $F_1 = \frac{M_1}{(d^2+l_1^2)^{3/2}} = H\tan\theta_1$

$F_2 = \frac{M_2}{(d^2+l_2^2)^{3/2}} = H\tan\theta_2$

Where F_1 and F_2 are the fields due to the two magnets acting on the magnetic needle which now lies on the equatorial line of the magnets. θ_1 and θ_2 are the mean deflections produced in the needle, successively due to the two magnets

[illegible] $\tan\theta_1$

(iv) $\frac{M_1}{M_2}=\frac{\tan\theta_1}{\tan\theta_2}$, if $l_1=l_2$ or if the half lengths l_1 and l_2 of the magnets are so small and the distance d is so large that l_1^2 and l_2^2 can be neglected compared with d^2.



Principle diagram

Fig. 13·2

Note—The magnetic needle should be shown quite small in length compared with the length of the magnet. Mark its poles and designate the ∠ made by the magnetic needle with the field H, as θ. Remember that since the magnetic needle lies on the equatorial line of the magnet, so the field F acting at the centre of the needle and through the centre is parallel to the magnetic axis of the magnet and in a direction from North pole side of the magnet towards the South pole side of the magnet.

Procedure

1. Examine tha apparatus and the working of its component very carefully.

2. *Setting the magnetometer in Tan B position. Remove all* magnets, magnetic materials and any other conductors carrying electric current *away from* the apparatus. First set the magnetometer *in Tan-A position by the method described in the last* Experiment and the pointer reads 0-0. Next hold the magnetometer from the extreme ends of its arms and rotate through 90° *so that the pointer reads 90-90. It means now the arms are* in the Noth-South direction, i. e., in magnetic meridian since the arms have been rotated through exactly 90° from their *East-West position in Tan A position. Before starting work rotate the* Compass box so that the pointer reads 0-0. Now the magnetometer is set in *Tan B* position.

3. *Note the breadths of the magnets and mark their* mid points. Distances are to be measured from the mid points of the magnet always. So *if practically distance from the edge of the magnet is observed, then to this distance, half the breadth of the* magnet should be added to know the exact distance from the *centre of the magnet.*

5. *Place the magnet* A, *on the* South arm *of* the magnetometer and with the axis of the magnet perpendicular to the arms and *in such a way that the pivot of the needle lies on the equato*rial line of the magnet. (In tangent A position, the axis *of the* magnet was along the arms and *not perpendicular to the arms*).

5. *Suppose the north pole of the magnet* is towards West. *Adjust the distance of the magnet so that the deflection obtained* is between 30° and 60°. *Note the deflection by reading both the ends of the pointer and also record the distance of the centre of the magnet from the pivot of the needle. This gives two readings.*

6. *Reverse the poles of the magnet so that now the north pole of the magnet points towards East. Read both the ends of the pointer, keeping distance of the magnet the same, this makes four readings.*

7. Next change the face of the magnet and repeat the four readings of steps (5) and (6), keeping distance of the magnet, the same. This makes 8 readings.

8. Transfer the same magnet on the other arm, i. e., North arm and keeping the centre of the magnet at the same distance as on South arm, repeat the above procedure and take 8 readings. This makes a total of sixteen readings for the same magnet A placed at the same distance d, on both the arms of the magnetometer. Take the mean of these sixteen deflections and say (θ_1).

9. Remove the magnet A away from the apparatus and place the magnet B in the same way and with its centre at the same distance. Repeat the same procedure to note the 16 deflections, the mean of which gives θ_2. This forms one set of observation.

10. Take such three sets of observations by changing the distance of the magnets.

11. Find $\frac{M_1}{M_2}$ separately for every set and take the mean.

Observations

Length of magnet A $=$ L ...cm, $l_1=\frac{5}{12}L=$...cm

Length of magnet B $=$ L ...cm, $l_2=\frac{5}{12}L=$...cm

Deflection of the pointer $=$ deflection of the magnetic needle

S. No.	Magnet	Distance of centre of the magnet d	Deflection of the pointer in degrees when the magnet is on the																Mean deflection (θ)	tan θ
			South Arm								North Arm									
			Face A up				Face B up				Face A up				Face B up					
			N-pole towards West		N-pole toward East		N-pole towards West		N-pole towards East		N-pole towards West		N-pole towards East		N-pole towards West		N-pole towards East			
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
1	A																			
	B																			
2	A																			
	B																			
3	A																			
	B																			

Calculations

$$\frac{M_1}{M_2} =$$

Result

Mean $\frac{M_1}{M_2} =$ ......(Being a ratio it has no units)

Precautions. Same as in the last experiment.

EXPERIMENT 13·3

Object—Compare the magnetic moments of two mangets by setting the deflection magnetometer in Tan A position of Gauss and using Null method.

Apparatus—Deflection magnetometer, two magnets and a metre rod.

Theory

The field F_A at the needle due to magnet A is counter-balanced by the field F_B due to the second magnet B, (the deflection being zero), So we have

(i) $$F_A = F_B$$

The magnetic needle lies on the magnetic axis of both the magnets, therefore

(ii) $$F_A = \frac{2M_1d_1}{(d_1^2-l_1^2)^2}$$

$$F_B = \frac{2M_2d_2}{(d_2^2-l_2^2)^2}$$

$$\therefore \quad \frac{2M_1d_1}{(d_1^2-l_1^2)^2} = \frac{2M_2d_2}{(d_2^2-l_2^2)^2}$$

or $$\frac{M_1}{M_2} = \frac{(d_1^2-l_1^2)^2}{(d_2^2-l_2^2)^2} \times \frac{d_2}{d_1}$$

(iii) $\frac{M_1}{M_2} = \frac{d_1^3}{d_2^3}$ if the magnets are so small that l_1^2 and l_2^2 are negligible compared with d_1^2 and d_2^2 respectively.

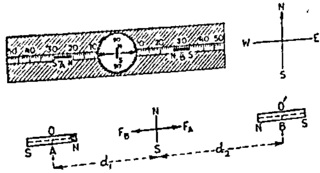


Fig. 13·3

Procedure

1. Mark the magnets as A and B, measure their lengths and mark their mid points.

2. Set the magnetometer in the Tan A position as discussed earlier. The arms are therefore in the East-West direction and the pointer reads 0-0.

3. Place the magnet A with its mid point at a distance d_1 kept fixed always) on the East arm of the magnetometer and with its North pole towards the needle. Deflection should not be very small. Then place the other magnet B on the West arm of the magnetometer and with its north pole towards the needle. This magnet deflects the needle in the opposite direction. Move the magnet B along the arm and find a position for which the magnetic needle stands at 0–0 again. It means deflection produced by B is exactly equal and opposite to the deflection produced by A so that the net deflection is zero. This is so because the couple on the needle due to one magnet is exactly equal and opposite to the couple due to the other. Note the distance of the centre of the magnet B.

4. Now reverse the poles of the magnet A on the same East arm so that its south pole now points towards the needle, the distance of its mid point from the needle being kept the same, equal to d_1 as before.

You will have to reverse the poles of the magnet B also, on ... its position to get zero deflection.

Note the distance of the centre of the magnet B, from the needle. This makes two readings.

5. Turn the magnet B upside down and reverse its face. Adjust its distance to get zero deflection again. Note the distance of the centre of the magnet. This makes three readings.

6. Reverse the poles of A. Then the poles of B will also have to be reversed and again the distance of B, adjusted to get zero deflection. Note the distance of B again. This makes four readings.

7. Now place the magnet A first with its N-pole and then S-pole towards the needle, on the West arm of the magnetometer, keeping the distance d_1 of its centre from the needle, the same as on the East Arm. Note the corresponding distances of the centre of the magnet B, which is now placed on the East Arm and whose position is adjusted to get zero deflection. These two readings along with four, already taken make six readings.

Next reverse the face of magnet B and note its distances first when N—pole of both the magnets A and B are towards the needle and again when S—poles of both the magnets A and B are towards the needle. This makes 8 readings. Let mean of these eight readings be d_2. This forms one set.

8. Repeat the experiment by placing magnet A, at two more fixed distances. Thus three sets of observations are obtained.

9. Calculate $\frac{M_1}{M_2}$ separately for every set and then calculate the mean $\frac{M_1}{M_2}$.

Observations

Length of magnet A = L ...cm, $l_1 = \frac{5}{12}L = ...$cm

Length of magnet B = L ...cm, $l_2 = \frac{5}{12}L = ...$cm

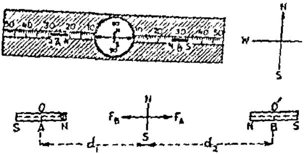


Fig. 13·3

Procedure

1. *Mark the magnets as* A *and* B, *measure their* *lengtl* *mark their mid points.*

2. *Set the magnetometer in the* Tan A *position as disc* *earlier. The arms are therefore in the East-West direction an* *pointer reads 0-0.*

3. Place *the magnet A with its mid point at a distan kept fixed always) on the East arm of the magnetometer with its North pole towards the needle. Deflection should nc very small.* Then place the other magnet B on the West arı the magnetometer and with its north pole towards the nee This magnet deflects the needle in the opposite direction. M the magnet B along the arm and find a position for which magnetic needle stands at 0–0 again. It means deflection pro ced by B is exactly equal and opposite to the deflection pr by A so that the *net deflection is zero.* This is so couple on the needle due to *one magnet is exactly* opposite to the couple due to the other. Note the distan centre of the magnet B.

4. Now reverse the poles of the magnet A on arm so that its south pole now points towards *distance of its mid point from the needle* equal to d_1 as before.

You will have to reverse the poles of the same West arm and adjust its position tc

Calculations—(1) $\frac{M_1}{M_2}=$

Result

Mean $\frac{M_1}{M_2}=$ ... (Being a ratio, it has no units).

Precautions—In addition to the general precautions to be observed with a deflection magnetometer, the following precautions are note worthy.

1. Both the ends of the pointer may not read zero before starting the experiment. Hence while setting the instrument, make only one end read zero. Do not bother about the other. Then in all subsequent readings in the experiment, the same end is to be brought to zero always by adjusting the distance of magnet B.

9. Similar poles of both the magnets should point towards the needle so that their fields may be opposite otherwise zero deflection will not be obtained.

3. In one particular set, distance of one magnet (A) is to be kept fixed and distance of only the other magnet (B) is to be adjusted in the eight readings to be obtained, to get zero deflection every time.

Oral Quetions

1. Which setting for the magnetometer you prefer ? Tan A or Tan B.

Ans—Tan A position is preferred because the field due to the same magnet placed at the same distance is twice in Tan A position than in Tan B position, Therefor the same magnet and for the same distance, the deflection produced in Tan-A setting will be more. Consequently the accuracy in measuring deflection will be more.

2. Which method do you prefer for comparing the magnetic moments of two magnets, deflection method or null method and why ?

Ans. Null method is preferred because the deflection in this method is zero, always. So deflection is not to be measured and therefore the errors which could be committed in measuring the deflection, are eliminated.

S. No.	Fixed distance of the mid pt. of magnet A (d_1)	Distance of the mid pt of the magnet B from the needle when B is on								Mean d_2	$\frac{M_1}{M_2} =$
		West Arm				East Arm					
		Face A up		Face B up		Face A up		Face B up			
		N—pole towards needle	S—pole towards needle	N—pole towards needle	S—pole towards needle	N—pole towards needle	S—pole towards needle	N—pole towards needle	S—pole towards needle		
1	cm										
2	cm										
3	cm										

Calculations—(1) $\frac{M_1}{M_2}=$

Result

Mean $\frac{M_1}{M_2}=$ ... (Being a ratio, it has no units).

Precautions—In addition to the general precautions to be observed with a deflection magnetometer, the following precautions are note worthy.

1. Both the ends of the pointer may not read zero before starting the experiment. Hence while setting the instrument, make only one end read zero. Do not bother about the other. Then in all subsequent readings in the experiment, the same end is to be brought to zero always by adjusting the distance of magnet B.

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Oral Quetions

1. Which setting for the magnetometer you prefer ? Tan A or Tan B.

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Ans. Null method is preferred because the deflection in this method is zero, always. So deflection is not to be measured and therefore the errors which could be committed in measuring the deflection, are eliminated.

tance of centre of the magnet B, each time. This mak readings.

6. Then transfer the magnet A on to the North Arm a magnet B on to the South arm. Keeping the distance of of the magnet A, the same, i.e., d_1 as on the South arm, repe above process and take the four readings of the distance of of the magnet B, when B is placed on the other arm, i. e., arm. So eight readings of the distance of magnet B hav obtained corresponding to fixed distance d_1 of magnet A mean of these eight readings be d_2. This forms one set.

7. Repeat the experiment by placing magnet A, at two fixed distances. Thus three sets of observations are obtaine

8. Calculate $\frac{M_1}{M_2}$ separately for every set and find mea

Observations

Length of magnet $A = L$ ......cm, $l_1 = \frac{5}{12} L =$

...f the mid point of magnet B from the needle when B is on							Mean d_2 in cm	$\frac{M_1}{M_2}$
...orth Arm			South Arm					
	Face B up		Face A up		Face B up			
...ole ...rds ...t	N—pole towards West	N—pole towads East	N—pole towards West	N—pole towards East	N—pole towards West	N—pole towards East		

Calculations

(1) $\frac{M_1}{M_2}=$

Result

Mean $\frac{M_1}{M_2}=$......*(Being a ratio, is has no units).*

Precautions :—Same as in the previous experiment,

Modifications

EXPERIMENT 13.5

Object—Plot a graph between $\frac{(d^2-l^2)^2}{2d}$ and $\cot\theta$ for different values of d and mean θ in Tan A setting of the deflection magnetometer. Interpret this graph. (R. U. 1966)

Hint

Theory

$$F=\frac{2Md}{(d^2-l^2)^2}=H\tan\theta \text{ (for Tan A position)}$$

$$\text{So } \frac{M}{H}=\frac{(d^2-l^2)^2}{2d}\tan\theta$$

Now $\frac{M}{H}=$ constt. (K) for a magnet and for a particular place

$$\therefore \quad \frac{K}{\tan\theta}=\frac{(d^2-l^2)^2}{2d}$$

$$\text{or } \frac{(d^2-l^2)^2}{2d}=K\cot\theta \left(\because \frac{1}{\tan\theta}=\cot\theta\right)$$

$$\text{i.e. } \frac{(d^2-l^2)^2}{2d}\propto\cot\theta$$

Hence graph between $\frac{(d^2-l^2)^2}{2d}$ and $\cot\theta$ will be a straight line.

Remember that $\cot\theta=\tan(90-\theta)$

Examples $\cot 38°=\tan(90-38)=\tan 52°$

$\cot 60°=\tan 30°$

So it is easier to calculate cot of an angle by consulting natural tangent tables. The value of tan 30° will be the same as that of cot 60°.

EXPERIMENT 13.6

Object – Verify Inverse square law of magnetism with the help of deflection magnetometer.

Theory

A magnet of magnetic moment M and length $2l$ is placed at a distance d from the magnetic needle. Let θ and ϕ be the mean deflections obtained when the magnetometer is set in Tan A and Tan B positions respectively. F_A and F_B are the fields due to the same magnet, acting on the needle when magnetometer is set in Tan A and Tan B positions respectively.

$$F_A = \frac{2Md}{(d^2-l^2)^2} = H \tan\theta \qquad \ldots\ldots(1)$$

$$F_B = \frac{M}{(d^2+l^2)^{3/2}} = H \tan\phi \qquad \ldots\ldots(2)$$

$$\text{Dividing} = \frac{2d(d^2+l^2)^{3/2}}{(d^2-l^2)^2} = \frac{\tan\theta}{\tan\phi} \qquad \ldots\ldots(3)$$

Procedure

Place a magnet at a distance d on the arm of a magnetometer set in Tan A position and find the mean θ of the 16 deflections obtained.

Then set the magnetometer in Tan B position. Place the same magnet at the same distance d on its arm and find the mean ϕ of the 16 deflections obtained. Then show that equation (3) is true. Equation (3) has been deduced from equations which were derived on the basis of inverse square law. So if practically, equation (3) is verified to be true, it means inverse square law has been indirectly verified to be true.

14

VIBRATIO[N] MAGNETOMETE[R]

EXPERIMENT 14.1

Object—Compare the magnetic moments of two magnets ***vibration magnetometer using moment of inertia method.***

Apparatus—Vibration magnetometer, two magnets, spi[rit] level, compass needle, a brass bar, stop watch, vernier callipe[rs] or metre rod, physical balance and weight box.

Theory

When a magnet suspended freely from its centre of gravity i[s] displaced through an $\angle\theta$ from its natural position in the magneti[c] meridian, a couple MH sin θ acts on the magnet and the magne[t] begins to oscillate with a small amplitude in a horizontal plan[e] about the vertical axis passing through its centre of gravity. It[s] time period is given by

(i) $T_1 = 2\pi\sqrt{\dfrac{I_1}{M_1H}}$

Where H = the horizontal component of Earths field.

I_1 = the moment of inertia of the magnet about its axis of oscillation,

and T_1 = the time period of first magnet.

(ii) $T_2 = 2\pi\sqrt{\dfrac{I_2}{M_2H}}$ for the second magnet.

(iii) $\dfrac{M_1}{M_2} = \dfrac{I_1}{I_2} \times \dfrac{T_2^2}{T_1^2}$

(iv) $I = \text{Mass} \times \left[\dfrac{(Length)^2 + (Breadth)^2}{12}\right]$

i. e., $I=m\left[\frac{L^2+B^2}{12}\right]$ for a rectangular bar magnet

and $I=m\left[\frac{L^2}{12}+\frac{R^2}{4}\right]$ for a cylindrical magnet

when R = the radius of the cylindrical magnet
m = its mass

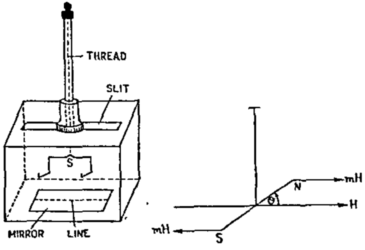


Fig. 14·1

Couple $=MH\sin\theta$

Procedure

1. Level the vibration magnetometer with the help of a spirit level by adjusting the levelling screws. When levelled, the suspension thread will not touch the sides. It will pass through the centre of the hole.

2. **To set the magnetometer in the magnetic meridian.** A line is already marked on the plane mirror fixed to the floor of the magnetometer. The line is parallel to the slit. Place a compass needle on this line and rotate the box till the compass needle becomes parallel to the line. Mark the boundary line around the box which now lies in the magnetic meridian.

3. $I_1 = m_1 \left[\frac{L_1^2+B_1^2}{12}\right]$

$= \text{............gm cm}^2$

4. $I_2 = m_2 \left[\frac{L_2^2+B_2^2}{12}\right]$

$= \text{............gm cm}^2$

5. $\frac{M_1}{M_2} = \frac{I_1}{I_2} \times \frac{T_2^2}{T_1^2}$

i. e., $\frac{M_1}{M_2} =$ .... Being a ratio, it has got no units.

Precautions

1. The suspension fibre should be carefully chosen; it should be free from twist. Unspun silken thread serves best.

2. No magnetic substance should be present in the neighbourhood of the magnetometer.

3. No metal should be present in its vicinity because this vibrating magnet would cause the flow of eddy currents in that metal, due to the variation of magnetic flux in the metal. *Consequently the vibrations will get damped and the time period will be affected.*

4. The formula holds good only for small amplitudes (i.e. in which $\sin\theta = \theta$). So see that the amplitude does not exceed 5°.

5. Before starting the experiment, the magnetometer should be set in the magnetic meridian and twist in the thread, if any, should be *removed according to step 3 of the procedure given above.*

6. The axis of suspension should pass through the centre of gravity of the magnet.

7. When the magnet is placed *in the stirrup, see that the* plane containing the length and the breadth of the magnet remains horizontal. This is necessary so that the *horizontal component of earth's field alone should act on the magnet.*

8. The magnet should be small so that it vibrates in a *uniform field.* Its north pole should point towards geographical north of the earth. *So before starting the experiment check the poles of the magnets and see that the magnets are not demagnetised.*

9. For counting the number of vibrations, count ZERO and not ONE, when the magnet passes through the magnetic meridian and simultaneously the stop watch is started.

10. Remember length and breadth of the magnet are those dimensions of the magnet, which are perpendicular to the suspension thread and thickness is parallel to the axis of suspension. Don't confuse breadth with thickness.

11. Note the time very carefully, twice for the same number of vibrations. In the table, record the time in minutes and seconds as read on the stop watch. Then convert minutes into seconds.

Sources of error

1. The suspension thread is not completely free from twist. So a couple due to twist acts and causes an error.

2. When the magnet is set to be horizontal, (so that only the field H acts on the magnet), the centre of gravity of the magnet is NOT exactly below the point of suspension. The reason for this is that the moment of the couple due to vertical component of earth's field, acting on the magnet has to be balanced by the moment due to weight of the magnet, when magnet is horizontal. Hence there occurs an error in the measurement of radius of gyration and hence in the measurement of moment of inertia.

3. Damping also affects the time period.

4. Amplitude can not be decreased very much, practically but theoretically it is required to be small.

Oral Questions

1. Why the apparatus is made of wood? Are there no iron nails fixed in it? What is the use of the mirror fixed to its floor? Why above the apparatus, the tube, through which the thread passes, is of glass? Why the sides of the magnetometer box have glass sheets?

2. Will you prefer a magnetometer box of long glass tube or small tube?

Ans—The time period of oscillation is independent of the length of the suspension thread. Still we prefer a long vertical glass tube to have a greater length of suspension thread. The effect of torsion in the suspension, if any, will become negligible, if the suspension is long.

3. In which direction a freely suspended magnet would point? *On being deflected, why this freely suspended magnet vibrates?* What is the nature of these vibrations?

4. Upon what factors does the time period depend? How the time period of the magnet changes, when we go from the equator to the poles?

5. Will you chose a magnet of large magnetic moment? Of what material, the magnets are made?

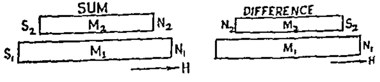
6. *What is the principle of this experiment?*

7. *What is the use of the stirrup?*

8. What is moment of inertia and what are its units?

EXPERIMENT 14.2

Object—Using vibration magnetometer, compare the magntic moments of two magnets by sum and difference method.



$M = M_1 + M_2$ $\qquad$ $M = M_1 - M_2$

$I = I_1 + I_2$ $\qquad$ $I = I_1 + I_2$

time period $= T_1$ $\qquad$ *time period* $= T_2$

Theory and formula

T_1 is the time period in the sum reading, i.e., when N-poles of both the magnets point towards geographical north of the earth.

T_2 is the time period in the difference reading, i.e., when N-pole of the stronger magnet is towards North of the earth and N-pole of the weaker magnet is towards South of the earth.

The moment of inertia $I = I_1 + I_2$, of the combination remains the same in the sum reading and also the difference reading. The total magnetic moment $M = M_1 + M_2$ in the sum reading and $M = M_1 - M_2$, in the difference reading.

$$T_1 = 2\pi \sqrt{\frac{I_1 + I_2}{(M_1 + M_2)H}} \quad ....(1)$$

$$T_2 = 2\pi \sqrt{\frac{I_1 + I_2}{(M_1 - M_2)H}} \quad .(2)$$

Squaring (1) and (2) we get

$$T_1^2 = 4\pi^2 \frac{I_1 + I_2}{(M_1 + M_2)H} \quad .(3)$$

$$T_2^2 = 4\pi^2 \frac{I_1 + I_2}{(M_1 - M_2)H} \quad ....(4)$$

Dividing (4) by (3)

$$\frac{M_1 + M_2}{M_1 - M_2} = \frac{T_2^2}{T_1^2} \quad .$$

Apply componendo and dividendo.

$$\frac{M_1}{M_2} = \frac{T_2^2 + T_1^2}{T_2^2 - T_1^2} \quad ....(5)$$

Procedure

Steps 1 to 3 are exactly the same as described in experiment No. 14.1 above.

4. First of all check the poles of the two given magnets. Be sure that neither of the two magnets is demagnetised. If one magnet is demagnetised, T_2 will be the same as T_1 and the denominator in (5) will become zero and $\frac{M_1}{M_2}$ will come out to be ∞, which is NOT possible.

5. Test which of the magnets is stronger. For this, place the magnets by turn, on the arm of a deflection magnetometer, at the same distance. The one which produces a greater deflection in the needle of the deflection magnetometer, is stronger.

6. Place in the stirrup the two magnets symmetrically one above the other, with similar poles pointing towards north of the earth. A piece of paper or cardboard is inserted between two magnets so that they do not induce polarity on each other. If two pairs of hooks are provided in the stirrup, then one magnet should be placed in the upper hook and the other magnet in the lower hook. Since now they are a good distance apart, they won't induce polarity and hence there is no need of placing any cardboard between them.

The combination is ready for sum-observation. Its time period T_1 is observed.

7. For the difference reading, shift the north pole of the weaker magnet from north towards south of the earth. Keep the North pole of the stronger magnet toward North of the earth, otherwise the combination of the magnets will rotate through 180°. Note the time period of this combination. It is T_2.

8. Calculate $\frac{M_1}{M_2}$ using formula (5) above.

Observations

S. No.	Number of vibrations	Sum Reading			Difference reading		
		Time in Minutes and seconds	Time in secs.	Time Period T_1 (sec.)	Time in Min. and sec.	Time in secs.	Time Period T_2 (sec.)
1	20						
2	20						
3	25						
4	25						
5	30						
6	30						

Mean $T_1 = 14{\cdot}7$ seconds (say)

Mean $T_2 = 35{\cdot}3$ seconds (say)

Calculations

$$\frac{M_1}{M_2} = \frac{T_2^2 + T_1^2}{T_2^2 - T_1^2}$$

$$= \frac{(35{\cdot}3)^2 + (14{\cdot}7)^2}{(35{\cdot}3)^2 - (14{\cdot}7)^2}$$

$\log 35{\cdot}3 = 1{\cdot}5478$

$\times 2$

antilog $3{\cdot}0956$

$= 1247$

$$= \frac{1247{\cdot}0 + 216{\cdot}1}{1247{\cdot}0 - 216{\cdot}1}$$

$\log 14{\cdot}7 = 1{\cdot}1673$

$\times 2$

antilog $2{\cdot}3346$

$= 216{\cdot}1$

$$= \frac{1463{\cdot}1}{1030{\cdot}9}$$

$\log 1463 = 3{\cdot}1653$

$\log 1031 = 3{\cdot}0133$

antilog $\overline{0{\cdot}1520}$

$= 1{\cdot}419$

$\therefore$ Result $\dfrac{M_1}{M_2} = 1{\cdot}419$

Being a ratio, $\dfrac{M_1}{M_2}$ has no units.

Additional Precautions

1. Don't allow the magnets to touch each other. They will induce polarity on each other and thus cause error. So either place cardboard between them or use such an apparatus in which they can be placed one above the other, 1 or 2 cm. apart.

2. If in the difference reading, the combination rotates through 180°, it means the North pole of the stronger magnet has been placed towards South of the earth. So change the poles of the magnets end to end.

3. The magnetic moments should not be nearly equal, because $M_1 - M_2$ will become very small in difference reading and hence period T_2 will become very large. If $M_1 = M_2$, $M_1 - M_2 = 0$, then $T_2 = \infty$. So it will be impossible to record any time period.

4. While changing from sum to difference reading, only the weaker magnet has to be reversed.

Sources of errors

1. Magnetic induction acting mutually on the two magnets will change the values of M_1 and M_2.

2. The geometrical axis and the magnetic axis of the magnets may not coincide.

Oral Questions

1. Why is this method called the sum and difference method? What is its importance and is this method better than inertia method? If so, why?

2. Why should the magnetic axis of the two magnets be parallel?

3. What is the necessity of the stirrup? Can't its use be avoided?

4. Should the stirrup be heavy or light?

Ans. It should be light, (i) If it is a heavy metallic stirrup the magnetic field of the earth will cause the flow of induced currents in the stirrup. This will damp the vibrations of the ... will increase on using a heavy

15

MEASUREMENT OF RESISTANCE

An unknown resistance can be determined by making use of Ohm's Law $R=\frac{V}{C}$. Thus the unknown resistance will be equal to the ratio of deflections obtained in the voltmeter and the ammeter. These deflections can not be determined accurately. Hence the value of R will not be accurate. If a method is evolved in which deflection remains zero and some other quantities are measured with a greater accuracy, such a method will be a NULL METHOD and hence preferable to the deflection method. Such a null method is based upon Wheatstone's bridge principle.

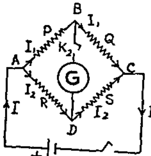


Fig. 15.1

A Wheatstone's bridge consists of four resistances P, Q, R and S connected as shown in the fig. 15·1. Between the points A and C, a cell along with a key K_1 is connected and between the points B

and D, a galvanometer along with a key K_2 is connected. On closing key K_1, current begins to flow through all the four resistances P, Q, R and S. Then on pressing key K_2, if galvanometer gives zero deflection, i.e., if no current flows in the branch B D, it means the resistances P, Q, R and S are such that potential at B = potential at D. This is possible when $\frac{P}{Q} = \frac{R}{S}$. Then bridge is said to be balanced.

Conclusion

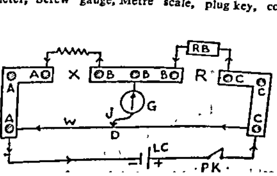
If the resistances P, Q, R and S are adjusted in such a way that on pressing first key K_1 and then key K_2, galvanometer gives zero deflection, it means the bridge is balanced and the condition $\frac{P}{Q} = \frac{R}{S}$ is being satisfied. Metre bridge and P. O. box are the practical examples of Wheatstone's bridge.

EXPERIMENT 15.1

Object—Using metre bridge, determine the resistance of the given wire and thus calculate the specific resistance of the material of the wire.

Apparatus

Metre bridge, decimal Ohm Resistance box, Leclanche cell, galvanometer, Screw gauge, Metre scale, plug key, connecting wires etc.



X — Unknown resistance, R. B–a decimal Ohm resistance box, LC—Leclanche cell, J- Jockey PK- plug key, G-Galvanometer, W — Metre bridge wire 100 cm long — AC

l — Balancing length corresponding to unknown resistance X.

ρ = resistance per cm length of the wire.

Theory and Formula

If galvanometer gives zero deflection when the jockey J is touched at the point D, it means the metre bridge is balanced and hence from equivalent Wheatstone's bridge diagram, we have

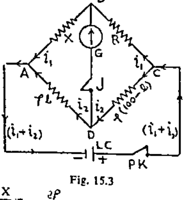


Fig. 15.3

$$\frac{X}{R} = \frac{l\rho}{(100-l)\rho}$$

i. e. $$\frac{X}{R} = \frac{l}{(100-l)}$$

(i) or $$X = R.\ \frac{l}{100-l}$$

Where l is the distance of the null point from the left end A of the wire, when unknown resistance X is in the left gap.

(ii) $$\rho = \frac{X.\pi r^2}{L}$$

Where ρ = Specific resistance of the material of the given wire.

r = radius of the given wire

L = the effective length of the wire, i. e., total length of the wire minus the length under the screws.

Procedure

1. Make the connections as shown in the *figure* 15·2. *If there* are four gaps in the apparatus, two of these may be closed by inserting two thick metal plates.

2. Start the current *in the circuit by closing the plug key.* Take out one or two ohm plug from the resistance box. Place the jockey J at one end A *of the wire* and note the galvanometer deflection. Then place the jockey *J* at the other end C of the wire and again note the *deflection. If these deflections* are in opposite directions, it means the connections are correct. For further confirmation, place the jockey *J* at the middle of the wire and note the deflections by making $R=0$ and $R=\infty$. The two deflections in opposite directions would mean the connections are correct.

3. Using resistances even up to first place of decimal, adjust *the resistance R in the R. B. in such a way that the null point is* obtained nearly at the middle of the wire. If null point is obtained *exactly at the middle of the wire, i. e., if the jockey J divides* the wire AC into two exactly equal halves, it would mean that the unknown *resistance X is equal to the resistance* R in the R. B. So without making calculations, is would give *you an idea about the exact magnitude of X,* which would be equal to R.

4. *With unknown resistance* X in the left gap, find the distance l' of the null point from *the left* end A of the wire. Interchange *the resistances* R and X, so that unknwon resistance X is now in the right gap. *Measure the distance* l'' *of the null point, from the right* end C of the wire. Take the mean of l' and l''. It is l. Use the *formula* $X=R\frac{l}{100-l}$, to calculate the unknown resistance X. *This is one set.*

Note—1. Note that l' and l'' correspond to X, i. e., these are the lengths measured on the side of X, always.

2. l' and l'' should not differ by more than 1 cm. Your observations will be considered better if l' and l'' are quite close to each other. So while interchanging the resistances, see that the portion of the wire under the screws

remains the same in the left gap as well as in the right gap. Also the pressure of connections should not change.

5. To take more sets, change R in R. B. in steps of ·1 ohm or ·2 ohm, i. e., take resistance in R Box = R−·2, R−·1, R, R+·1 and R+·2. So for these resistances used l should very preferably from 45 cm to 55 cm. In no case l should be less than 40 cm and more than 60 cm. So calculate X separately for these observations and then find the mean.

6. Disconnect the resistance wire and measure its length with the metre scale. As the portion of the wire under the screws does not contribute to resistance in the gap, hence exclude that portion while measuring length L of the wire.

7. With the help of a screw gauge, measure the diameter of the wire at six different points along the length of the wire and at every point in perpendicular directions. Find mean diameter D and then calculate its radius $r = \frac{D}{2}$.

8. Using the formula $\rho = X\ \frac{\pi r^2}{L}$, calculate the specific resistance ρ of the material of the given wire.

Observations

S. No.	Resistance in R. Box R (in ohms)	Distance of the null point from end A when X is in left gap l' (in cm)	Distance of the null point from end C when X is in right gap l'' (in cm)	$l = \frac{l' + l''}{2}$ (in cm)	(100−l) (in cm)	$X = R\frac{l}{(100-l)}$ (ohms)
1.						
2.						
3.						
4.						

Mean value of X = ...ohms.

Length L of the resistance wire = ...cms

Least count of the screw gauge = ...mm = ...cm

Zero error in screw gauge = ...mm = ...cm

S. No.		Main scale reading (in cms)	Circular scale reading		Tot readi
			in divisions	in cm	(in cm
1	(a) in one direction				
2	(b) in ⊥ direction				
:					
:					
:					
6					

Mean diameter = ... cm

Corrected diameter = D = ... cm

radius r = D/2 = ... cm

Calculations

$$\rho = R \cdot \frac{\pi r^2}{L}$$

Result

$\rho =$ ...... ohm cm

Precautions

2. Do not press the jockey on the wire, because it will make the cross-section of the wire non uniform. Although meter bridge is called slide wire bridge also yet do not slide the jockey by pressing it on the wire.

3. First press the plug key and then press the jockey j. If you press these keys in the reverse order, you are likly to miss the actual null point because galvanometer may give deflection due to the flow of induced current in it, even when the bridge is balanced.

4. To begin with, galvanometer may be shunted to avoid damage to its coil. Then near the null point the shunt may be removed.

5. The plugs in the resistance box should be tight. They should not be hammered down, but they should be rotated to make them tight. Whenever a particular plug is taken out, the plugs on either side of it get loose. So they should be tightened. Use decimal ohm box.

6. Allow the current to flow only for small time, because otherwise wire will get hot and its resistance may change. For the same reason, do not use a lead accumulator, as it will send a large current and thus heat the wire. So use Laclanche cell.

7. When the unknown resistance and the resistance box are interchanged, the distance of the null point should be measured from the other end of the wire.

8. Observations should be repeated after reversing the direction of current in the wire A C. So errors due to Peltier's effect will get eliminated.

9. X and R must be interchanged and while doing so the pressure of connections should not change. Do not include the wire that has come under the screws while measuring length L of the wire.

Sources of error

1. Due to non uniformity of the one metre long wire stretched on the metre bridge.

2. Due to end resistances.

3. Due to large least count equal to one mm for measuri length.

4. Due to Peltier's effect.

Oral Questions

1. *Why connecting wires are of copper and why are the* wrapped with thread ?

2. Define resistance, specific resistance, current, potentia difference and also name their units.

3. Why resistance wires are doubled on themselves before they are made into coils ?

4. Why resistance box is closed from all sides ? How the resistance coils are joined in it and what is there below the plug of infinite resistance.

5. Why galvanometer gives deflection on passing current and why its needle stops at a particular division when a particular current passed ?

6. What are other methods for determining the resistance and out of them which one is the best ?

7. Why metre bridge is called a metre bridge ? Can't the wire stretched on it be of copper. If not, why so ?

8. What are end resistances and how do they come into picture ?

9. Why the metallic plates joined in two gaps, so polished ?

10. What are conjugate arms ? When will the bridge be most sensitive ?

11. Can the metre bridge wire be taken very long or very short ?

EXPERIMENT 15.2

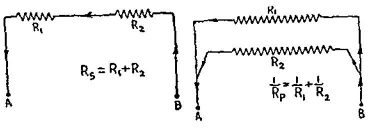
Object—Verify the laws of resistances in series and in parallels using metre bridge.

Formula

$$R_S = R_1 + R_2 \qquad \text{......(1)}$$

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} \qquad \text{......(2)}$$

When the resistances are joined in series, their equivalent resistance is equal to the sum of the individual resistances. When the resistances are joined in parallel, the reciprocal of their equivalent resistance is equal to the sum of the reciprocals of the individual resistances.



Series combination Parallel combination

Fig. 15.3

Procedure

1. Find the resistances R_1 and R_2 of the two resistance wires separately, according to the procedure given in experiment 15.1

2. Join R_1 and R_2 in series and connect this series combination in the left gap AB of the metre-bridge and find their equivalent resistance R_S. Disconnect them and again connect them, this time in parallel combination, in the gap AB of the metre bridge and determine their equivalent resistance R_P.

3. Then make a table as given on next page and show that is R_S very nearly equal to R_1+R_2 and $\frac{1}{R_P}$ is equal to $\frac{1}{R_1}+\frac{1}{R_2}$.

perimentally sured values								
R_2	R_S	R_P	$\frac{1}{R_1}$	$\frac{1}{R_2}$	$\frac{1}{R_P}$	$\frac{1}{R_1}+\frac{1}{R_2}$	$\frac{1}{R_P}-\left(\frac{1}{R_1}+\frac{1}{R_2}\right)$	$R_S-(R_1+R_2)$

sult

$R_S - (R_1 + R_2)$ = a very small quantity (negligible)

So $R_S = R_1 + R_2$ so law of resistances in series is rified. Again $\frac{1}{R_P} - \left(\frac{1}{R_1} + \frac{1}{R_2}\right)$ = a very small quantity negligible

So $\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2}$. So law of resistances in parallels verified.

ecautions

Don't take wires of very small resistances because in parallel mbination, the resistance will further decrease and hence the ror will increase.

Oral Questions

1. *What is the characteristic of series combination ?*

Ans. The same current passes through both the wires.

2. *What is the characteristic of parallel combination ?*

Ans. The same potential difference exists between the ends of both the wires.

3. *Where is series combination used ?*

Ans. (i) When it is *desired to decrease the current in the*

4. Where is parallel combination used ?

Ans. (i) When we want to increase the current in the circuit.

(ii) When the addition of one resistance is not desired to change the current in the other resistance.

Example—Electric bulbs are connected in parallels.

Note—The Equivalent resistance of a number of resistances connected in parallel is always less than the least of all of them.

Modifications

EXPERIMENT 15.3

Object— Study the variation of resistance of a wire of a given material with length.

Hint : $R \propto l$

Take three lengths l_1, l_2 and l_3 of the same wire, i. e., wire of the same material and the same diameter and find their resistances R_1, R_2 and R_3.

Then show that $\frac{R_1}{l_1} = \frac{R_2}{l_2} = \frac{R_3}{l_3}$ = constt.

i. e. $\frac{R}{l}$ = constt.

or $R \propto l$

Hence a graph between resistance and length will be a straight line.

EXPERIMENT 15.4

Object—Study the variation of resistance with diameter, by taking wires of the same material, and same length but of different diameters.

Hint : $R \propto \frac{1}{A}$ where A = area of cross-section of wire.

So $R \propto \frac{1}{D^2}$, $= \pi \frac{D^2}{4}$

Hence show that $R_1D_1^2 = R_2D^2 = R_3D_3^2$ = constt.

i. e., RD^2 = constt.

Also draw a graph between R and $\frac{1}{D^2}$. It will be a straight ine.

EXPERIMENT 15·5

Object—Determine the resistance of one cm length of the given wire by metre bridge.

$$\rho = \frac{R}{l} \text{ ohm per cm.}$$

Divide the resistance of a wire as determined by the help of metre bridge, by its length. It will be ρ, the resistance per cm length of the wire. You may take two or three different lengths and then calculate the mean value of ρ.

EXPERIMENT 15·6

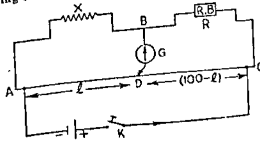
Object—Determine the length of the given wire required to construct a five ohm coil.

Let R be the resistance of length 1 cm of the wire determined as above in experiment 15.1. Then required length

$L = \frac{1}{R} \times 5$ cms.

EXPERIMENT 15·7

Object—Connect the unknown resistance X in one gap and a resis: tance box in the other gap. Then study a relation between resistance R in the resistance box and the reciprocal of the length corresponding to X.



$$R = \frac{(100-l)}{l} . X$$

$$R = \frac{100X}{l} - X \qquad ...(1)$$

X the unknown resistance is constant.

$$\text{Hence } R \propto \frac{1}{l} \qquad ...(2)$$

Hence a graph between resistance R in the R box and reciprocal of the length l (corresponding to unknown resistance X), will be a straight line.

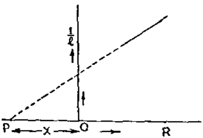


Fig. 15.5

Further on putting $\frac{1}{l} = 0$ in equation (1) we get,

$$R = 0 - X$$

$$\text{i. e., } X = -R$$

Hence if the straight line graph is produced, it will meet the axis of R, on its negative side at a point P whose distance from O, the origin would measure the unknown resistance X. So the unknown resistance X can be determined from this graph but since you have to find its absolute value, see that you take zero of $\frac{1}{l}$ and zero of R as the origin itself.

16

POST OFFICE BO

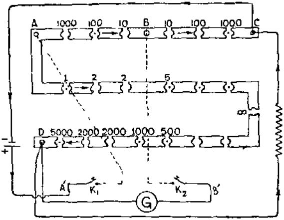
Post office box, like metre bridge is based on Wheatst bridge principle. Three arms P, Q and R of Wheatstone's br principle are permanently provided in the Post Office box it The fourth arm S is provided *from outside* by the unkn *resistance. Arms P and Q in the Post Office box are called* ratio arms and each arm contains resistance coils of 10, 100 a 1000 ohms joined in series. The third arm R is called the varia *resistance arm or the rheostat arm. It contains resistance co of one ohm, 2 ohms......and 5000 ohms, all joined in series. T* total resistance of all the coils in this arm R is 11110 ohms an the resistance in this arm can be varied in steps of one ohm, fro *one ohm to 11110 ohms.* The points A and B have been brough *out of A' and B' through tapping keys by making connection* internally as shown by dots.

For the measurement of resistance, metre bridge can cause *an error up to 5% and the P. O. box* can measure resistances up to second place *of decimal and with error less than 1%.* For very small resistances, it is not a good instrument but for ordinary resistances, it gives quick and accurate results. The resistance coils used in it are made of manganin which has a high specific *resistance and low temperature coefficient of resistance. To avoid the effect of water vapours present in air, the coils are sealed in* a closed box.

EXPERIMENT 16.1

Object—Using Post Office box, *determine the resistance of* the given wire and then calculate the specific resistance of the

Apparatus—Post office box, Leclanche cell, Galvanometer, Screw gauge, Metrescale, Connecting wires, Sand paper etc.



Post Office Box diagram

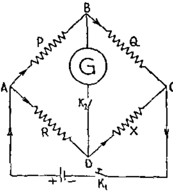


Fig. 16·1

Equivalent Wheatstone's bridge diagram

Theory and formula

If on pressing key K_1 and then key K_2, galvanometer gives zero deflection, it means the bridge is balanced and hence the condition

$$\frac{P}{Q}=\frac{R}{X}$$, is being satisfied and from

which $X=R\frac{Q}{P}$

Knowing P, Q and R, value of X, the unknown resista can be calculated. The ratio $\frac{Q}{P}$ can be kept as 1, 0·1 or (

$$\rho=\frac{X\pi r^2}{L} \text{ ohm cm}$$

where ρ = specific resistance of the material of wire.

r = radius of the wire measured in cm*,

L = Total length of the wire between the screws at measured in cms.

Procedure

1. Note carefully which points are internally connected in the Post office box and locate the points A, B, C and D. Make the connections as shown in the figure, i. e., insert the galvanometer between B and D via the tapping key B'. Connect the cell between A and C via the tapping key A'. Connect the unknown resistance between C and D, i. e., between the free ends of arms Q and R.

2. First of all take out 10 ohms plug from each of the arms P and Q.

Note :—If you do not do so, you won't get any deflection at all in the galvanometer. See that all the remaining plugs in the arms P, Q and R are tight.

To test whether the connections are correct or not, keep R = 0 and first press the cell key K_1 and then the galvanometer key K_2. Note the deflection. Next make R = ∞, and repeat the above process. If now the deflection is in a direction opposite to that obtained by keeping R = 0, it means, the connections are correct. If the deflection is in the same direction again, check up the connections and see that the one sided deflection is not due to loose plugs.

note the deflection. Go on increasing R in steps of one ohm, and note the direction of deflection every time. Thus find consecutive resistances (say 3 and 4 ohm) in arm R, for which deflections are obtained in opposite directions. Note these observations in the proper columns in the observation table. Since P and Q are equal. So the unknown resistance X is also equal to the resistance in third arm R, i.e., X lies somewhere between 3 and 4 ohms. **(Don't say X is equal to the mean of 3 and 4 ohm).**

4. Next make P = 100 Ωs, keeping Q = 10 Ω. Don't forget to introduce the 10 Ωs plug in P, because otherwise it will make P ≡ 110 Ωs. Now since P is ten times Q, from the formula $X = R\ \frac{Q}{P}$, it is clear that R will also have to be increased ten times, in order to get the null point. Hence search for consecutive resistances between 30 Ωs and 40 Ωs in R, for which galvanometer gives deflections in opposite directions. Let these be 37 Ωs and 38 Ωs. Unknown resistance X is now $\frac{1}{10}$ of the resistance in R, i. e., X lies somewhere between 3·7 Ωs and 3·8 Ωs (**Don't say that X is equal to the mean of 3·7 and 3·8 Ωs**). Record these observations in the table.

5. First insert 100 Ωs plug in P and then take out 1000 Ωs plug out of it, keeping Q = 10 Ωs as before so that the ratio Q.P becomes 10:1000. Now null point will be expected for obvious reasons, for some resistance lying between ten times the values of R obtained in step 4, i. e., between 370 and 380 Ωs.

6. At this stage the bridge usually becomes insensitive. Due to high resistance in the circuit, the current becomes very weak and so it does not produce any detectable deflection in the galvanometer. Therefore not down the *range* of all such resistances in R for which deflections remains zero. You MUST find two resistances, one on either side of this *range*, for which the galvanometer JUST gives deflections in opposite directions. Then the correct value of R is the mean of these values of R, which cause opposite deflections. This mean value of R divided by 100 gives the value of the unknown resistance X.

7. Measure the effective length L of the wire, (i. e., by excluding the portion of the wire under the screws) Measure the dia-

:ter of the wire at six different points all along the length of e wire and at every point in perpendicular directions. Find the :an diameter and hence the radius of the wire.

8. Calculate the specific resistance ρ, by using the formula $\sim X. \frac{\pi r^2}{L}$.

bservations

	Ratio arms P (ohms)	Ratio arms Q (ohms)	Resistance in Rheostat arm R (ohm)	Deflection is towards	Inference
1.	10	10	3 ∞	Right Left	Connections are correct.
2.	10	10	3 4	Right Left	$X=R\frac{Q}{P}=R.\frac{10}{10}=R$ So X lies somewhe between 3 and 4.
3.	100	10	37 38	Right Left	$X=R.\frac{10}{100}=\frac{R}{10}$. Tl refore X lies som where between 3. and 3.8
4.	1000	10	374 375 to 377 378	Right No deflection Left	$R = \frac{374+378}{2}=37$ $X = R.\frac{Q}{P}=R.\frac{10}{100}$ $=\frac{R}{100}$ $\therefore X = 3.76$ ohms.

So unknown resistance X = 3·76 ohms

(The values obtained in your experiment will naturally be different from those recorded in the above table).

Length of the resistance wire = L = ...cm.

S. No.		Main Scale reading (cms)	Circular scale reading		Total reading in cms
			in Division	in cms	
1	(a) in one direction				
	(b) in $\perp$ direction				
2					
......					
6					

$$\text{Mean diameter} = \frac{\ldots}{6} = \ldots\ldots\text{cm}$$

$$\text{Corrected diameter} = D = \ldots\ldots\text{cm}$$

$$\text{radius } r = \frac{D}{2} = \ldots\ldots\text{cm}$$

Calculations

$$\rho = \frac{X \cdot \pi r^2}{L}$$

Result

$$\rho = \ldots\ldots\text{ohm cm}$$

$$\text{Standard result } \rho = \ldots\ldots\text{ohm cm}$$

$$\%\text{age error} = \ldots\ldots$$

Precautions

1. All connections should be tight, neat and clean. Rub the connecting wires and the terminals with sand paper to make them clean.

2. When a plug is taken out, the plugs on either side of it get loose. Make them tight by slightly rotating. Repeat this every time when a plug is taken out. Do not hammer the plugs from above.

3. Never use an accumulator in this experiment. It will send a large current and then heat the resistances and change their values. Use a Leclanche cell.

4. *Always press the cell key first so that current grows to its constant value. Then press the galvanometer key. If galvanometer key is pressed first, then on pressing cell key, current grows in the circuit and consequently an induced current begins to flow in the circuit. This induced current may flow through the galvanometer and cause deflection in it even when the bridge is balanced. Thus you are likely to miss the actual null point.*

5. *Before testing the correctness of the connections, don't forget to take out 10 ohms plugs from each of the arms P and Q, because otherwise you won't get deflection at all in the galvanometer.*

6. Remember that *Q is kept fixed at 10 Ω* and only the *value of P is changed from 10 to 100 and then to 1000 ohms. While changing the value of P, see that only one plug is out, at a time.*

7. *When P : Q is 10 : 10, start with R = 0, 1, 2, 3...etc.* Sometimes when the unknown resistance X is less than one, i. e., it lies between 0 and 1, you will get one sided deflection if you try R = 1, 2, 3...upwards and if you do not record the deflection for R = 0. In this case on making P : Q as 100 : 10, the null point will be expected for some resistance R lying between 0 and 10 (0×10 = 0, and 1×10 = 10).

8. The values of R recorded for opposite deflections MUST be consecutive when P : Q is 10 : 10 or 100 : 10.

9. Remember that the unknown resistance *X* is obtained only from the third set. The first two sets, i. e., when P : Q is 10 : 10 or 100 : 10 only gives us an

3. In what respect the metre bridge method and post office box method, for the measurement of resistances are (i) similar (ii) different ?

Ans : (ii) In Post office box, ratio arms are kept fixed and resistance in third arm R is adjusted to get the null point. In Metre bridge, the ratio arms are themselves adjusted to get the null point.

4. When is the bridge most sensitive ? What are conjugate arms ? Explain.

5. Why in the last set, the bridge becomes so insensitive ?

6. Can't you keep P fixed at 10 ohms and change Q to 100 or 1000 Ω.

7. Is this the best method for determining the resistance ? To which place of decimal, the post office box can determine the unknown resistance ?

Modifications

1. Using Post Office Box, verify the laws of resistances in series and in parallels.

2. Study the variation of resistance of a wire of a given material and given diameter, with length.

3. Study the variation of resistance with diameter, by taking wires of the same material and the same length.

4. Determine the resistance per cm length of the given wire.

5. Determine the length of the given wire required to construct a one ohm coil. For the hints and solutions, consult the modifications on Metre bridge experiment, already discussed.

17

POTENTIOMETE

Potentiometer means the arrangement which measures potential difference.

Potentiometer is an ideal voltmeter. To cause deflection a voltmeter, current must pass through it. So when a voltmeter connected across two points to measure the potential differen between them, it draws same current. Hence the main curre between the two points decreases and consequently the potenti difference between the two points to be measured, also decrease Hence theoretically speaking, a voltmeter never reads the actua potential difference or the actual e. m. f. of a cell. Potentiomete is an arrangement in which no deflection is to be read. It is a NULL method and hence preferable. It measures the actual potential difference between two points and the actual e. m. f. of a cell.

EXPERIMENT 17·1

Object—Compare the e.m.f's. of two cells using potentiometer. Also find *the minimum and the maximum potential gradients you* have used in your experiment.

Apparatus—*Potentiometer,* Lead accumulator, Rheostate, plug key, two way key, galvanometer, the two cells say Leclanche cell and Daniel cell whose e. m. fs. are to be compared, *connecting wires* and jockey.

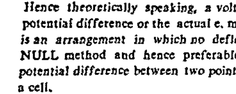


Fig. 17·1

PK=Plug key, LA=Lead *Accumulator, Rh=Rheostat,* LC=Leclanche cell; DC—Daniel cell. G=galvanometer. *J= Jockey.* TK=Two way key; AB=Potentiometer wire 1000 cm

long. It actually consists of ten wires joined in series and of 100 cm length each. D and D' are the null points obtained, after taking Leclanche cell and Daniel cell into the circuit respectively.

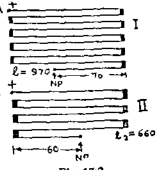


Fig. 17·2

Theory and Formula—Lead accumulator sends a constant current C (say) through the potentiometer wire A B, whose resistance per cm length of the wire is ρ l_1 and l_2 are the balancing lengths obtained with Leclanche cell and Daniel cell taken into the circuit respectively. Then if E_1 and E_2 are the e.m. f's. of Leclanche cell and Daniel cell, we have

E_1 = Potential difference between A and D = $C\, l_1 \rho$

E_2 = Potential difference between A and D' = $C\, l_2 \rho$

$$\text{so} \quad \frac{E_1}{E_2} = \frac{C\, l_1 \rho}{C\, l_2 \rho} \text{ i.e. } \frac{E_1}{E_2} = \frac{l_1}{l_2} \qquad \dots (1)$$

i. e., e. m. fs. of the two cells are directly proportional to their balancing lengths provided constant current is passed through the potentiometer wire.

Potential gradient κ is the potential difference per unit length of the potentiometer wire

$$\text{i. e. } \kappa = \frac{E_1}{l_1} = \frac{E_2}{l_2} = C\rho \qquad \dots (2)$$

Since e.m.f. of Daniel cell is taken as a standard e.m.f. = 1·08 volts, so

$$\text{Minimum potential gradient used} = \kappa_{\text{min}} = \frac{\text{E. m. f. of Daniel cell}}{\text{Max. value of } l_2 \text{ out of all sets of observations}}$$

$$\text{Maximum potential gradient used} = \kappa_{\text{max.}} = \frac{\text{E. m. f. of Daniel cell}}{\text{Min. value of } l_2 \text{ out of all sets of observations}}$$

Units of potential gradient are volts per cm.

Procedure—1, Make the connections as shown in the fig 17·1 i.e., first join in series the plug key, the lead accumulator a the rheostat between the ends A and B of the potentiometer w so that a current begins to flow through A B. Next connect t positive electrodes of both the given cells at the same end where positive pole of the lead accumulator has already been connected. The negative electrodes of the two given cells are joined to the end terminals of the *two way key whose central terminal* is connected to one terminal of the galvanometer. The other terminal of the galvanometer is connected to the jockey J sliding over the potentiometer wire.

2. **Testing the connections**—Start the current in wire A B by inserting a plug in the plug key. Next being Leclanche cell (i. e. cell of higher e.m.f.) into the circuit by inserting the plug 1 in the two way key. Place the jockey J on the first wire and then on the last wire. If galvanometer gives deflections in opposite directions in these two cases, it means the connections are *correct. If the* deflection remains one sided, check up the connections and see that the positive pole of the lead accumulator, and positive electrods of Leclanche cell and Daniel cell are all connected to the common point A. If the connections are correct and still one sided deflection is obtained on the first wire and on the last wire, it means the potential difference between A and B is less than the e.m. f. E_1 of the cell, so to increase the potential difference between A and B, increase the current C flowing in the potentiometer wire A B.

(i) *by decreasing the resistance in the primary circuit* with the help of rheostat

or (ii) by inserting another lead accumulator *in series* with *the first in the primary circuit.*

Again check and see that deflections in opposite directions are obtained on the first wire and on the last wire.

3. *After testing the connections and after the necessary* adjustment, explained in step 2, search for the null point and preferably get the null point on the last wire, by adjusting the resistance with the help of rheostat, if necessary. This is done so, because greater the balancing length obtained, smaller will be the

percentage error. Note the balancing length, i. e., measure the distance of null point D from end A of the wire.

Note—Distances of null points are to be measured always from the end A, i. e., where positive pole of the battery and positive electrodes of the cells are all connected. Note these distances very carefully. The students usually read 970 as 930 and 660 as 640 (See the figure 17·2).

4. Next take out plug 1 and insert plug 2 in the two way key so that the other cell (Daniel cell) comes into the circuit. Without disturbing the rheostat (otherwise current C will change), balance the e.m.f. E_2 of this cell against length l_2 of the potentiometer wire. These values of l_1, l_2 constitute one set of observations. Calculate $\frac{E_1}{E_2}$

5 Next change ε, the potential gradient by adjusting the rheostat and take another set of l_1 and l_2. In all, 12 to 15 sets may be taken.

Note: - In a particular set, while determining l_1 and l_2, the rheostat should not be disturbed.

Calculate $\frac{E_1}{E_2}$ separately for every set and then take the mean.

Observations and calculations

S. No.	Balancing Length for leclanche cell l_1 in cms.	Balancing length for Daniel cell l_2 in cms.	log l_1	log l_2	$x = \log l_1 - \log l_2$	$\frac{E_1}{E_2} = \frac{l_1}{l_2}$ = Antilog x
1	992·7	675·4				
2	970·0	660·0				
⋮	⋮	⋮				
15	⋮	432·8				

Mean $\frac{E_1}{E_2}$ = ... Being a ratio of two similar quantities $\frac{E_1}{E_2}$ has got no units.

Maximum value of Balancing length used for Daniel cell = 675.4 cm.

Minimum " " " used for Daniel cell = 432.8 cm.

and e. m. f of Daniel cell = 1.08 volts (given).

So Minimum potential gradient used $= \frac{1.08}{675.4} =$ ...... volts/cm.

Maximum " " " $= \frac{1.08}{432.8} =$ ...... volts/cm.

Precautions

1. The positive electrodes of the two cells and the positive pole of the Lead accumulator, all the three must be connected at one point A

2. Choose the lead accumulator of large capacity (in ampere hours) so that current through the potentiometer wire remains steady throughout the experiment.

3. The galvanometer should be shunted to begin with and when the null point is reached, the shunt should be removed.

4. As soon as the null point is determined, open the plug key PK, so that the potentiometer wire does not get unnecessarily heated up.

5. The potential difference between the ends A and B of the wire must be greater than th
taken individually otherwis
deflection will remain one
first check up the conneci
increase the current through
increase the number of lead

6. Better get the null poi
cell in circuit, because greater
... error.

7. First balance the cell of higher e. m. f. (Leclanche cell). If you balance the cell of lower e.m.f. (Daniel cell) first and get the balancing length = 950 cm (say), then with Leclanche cell in the circuit, the balancing length required will be more than 1000 cm, which is not available.

8. Do not disturb the position of the slider on the rheostat i. e., do not change the current through the wire for one set of l_1 and l_2.

9. Starting with balancing length more than 900 cm for the Leclanche cell control the experiment in such a way that balancing length for Leclanche cell in the succeeding sets is obtained in the decreasing order at a spacing of about 15 to 20 cm. For this, you will have to slide the slider on the rheostat only in ONE direction.

10. Distance of the null point MUST always be measured from the point A where all +ive terminals have been connected. If the null point is obtained on an odd number of wire (3, 5, 7, 9), the reading of the jockey on the scale should be added as such to the full metre lengths (2, 4, 6, and 8 respectively) of wire from A. If null point occurs on an even number of wire (2, 4, 6, 8, 10), the reading of the jockey on the scale should be first subtracted from 100 and then difference added to the full metre lengths (1, 3, 5, 7,9 respectively) of wire from A.

Sources of error can be due to—

1. Non uniform radius of the potentiometer wire.

2. End resistances.

3. Any variation in the e.m.f. of the lead accumulator which is sending current through the wire.

Oral Questions

1. Why potentiometer is so called ? Define potential gradient. What are its units ?

2. Both the potentiometer and the voltmeter are used to measure the potential difference between two points; which instrument is better and why ? Explain the principle of the potentiometer.

3. Why potentiometer is called an ideal voltmeter? Will you choose a voltmeter of higher resistance or lower resistance? Give reasons for your answer.

4. Why is it necessary to connect all the positive terminals at one point? Can't the experiment be performed by connecting all the negative terminals at one point.

5. Why the e.m.f. of lead accumulator should be greater than the individual e.m.fs. of the two cells? Why the cell of higher e.m.f. should be balanced first?

6. If the jockey J is touched at a point to the left or to the right of the actual null point, the galvanometer gives deflection. Trace the direction of current through the galvanometer in each such case.

7. Why rheostat is not disturbed while taking one set of l_1 and l_2.

8. Why the potentiometer consists of so many wires, i.e., ten wires? Are these joined in series or in parallels.

9. What will you do, if for the same cell, you want to

(i) increase the balancing length,

(ii) decrease the balancing length?

10. What are the uses of potentiometer?

Modification

EXPERIMENT 17·2

Object-Determine the e.m.f. of Leclanche cell after standardising the potentiometer wire with the help of Daniel cell. Also set up a potential gradient of 2 milli volts per cm along the wire and then find the balancing length for the Leclanche cell. Given e.m.f. of Daniel cell = 1·08 volts. (Raj. Univ. 1966)

Hint: Proceed for the experimental details exactly in the same manner as under Expt. 17·1, i.e., first balance the Leclanche ... then Daniel cell. Take

Theory

(a) If a Leclanche cell of e.m.f. E_1 and Daniel cell of e.m.f. $E_2 = 1{\cdot}08$ volts (given) are balanced against lengths l_1 and l_2 respectively of the potentiometer wire carrying a constant current,

$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$

$$\text{i. e.,} \quad E_1 = \frac{E_2}{l_2} \times l_1 \qquad \ldots(1)$$

$\frac{E_2}{l_2} = \frac{1{\cdot}08}{l_2} = \sigma$, the potential gradient obtained along the wire

$$\text{So } E_1 = \sigma l_1, \qquad \ldots(2)$$

where l_1 is measured in cms, σ in volts/cm and therefore E_1 is given in volts.

(b) How to set up a potential gradient of 2 milli volts/cm ?

$$\sigma = \frac{E_2}{l_2}$$

$$\text{i.e.,} \quad 2 \times 10^{-3} = \frac{1{\cdot}08}{l_2}$$

$$\text{or} \quad l_2 = \frac{1{\cdot}08}{2 \times 10^{-3}}$$

$$\text{i.e.,} \quad l_2 = \frac{1080}{2} = 540 \text{ cm}$$

So current flowing through the potentiometer wire should be so adjusted that the Daniel cell is balanced against length 540 cm of the potentiometer wire.

Observations and Calculations

S. No.	Balancing length for Leclanche cell l_1 in cms	Balancing length for Daniel cell l_2 (in cms)	Potential gradient obtained $\sigma = \frac{E_2}{l_2} = \frac{1 \cdot 08}{l_2}$	e.m.f. of Leclanche $E_1 = \sigma l$
1.			......Volts/cm	V
2.				
...				
...				
...				
...				
10				

Mean e.m.f. of Leclanche cell = ...volts

To set up a potential gradient of 2 millivolts/cm, place t jockey at a distance of 540 cm (as calculated above in theory) fro the end A of the wire and adjust the position of the slider on t. rheostat so that galvanometer reads zero deflection. After th setting is made, do not disturb the rheostat and find the balancir length for Leclanche cell. See that this balancing *length mult plied by 2×10^{-5} gives a result equal to the mean* value of e.m.f. c Leclanche cell already determined.

Modifications

EXPERIMENT 17.3

Object—*Using potentiometer, determine the internal* **resistance of a primary cell (say Leclanche cell).**

Apparatus

Potentiometer, an accumulator, a rheostat, two one way plug ...istance box, Leclanche cell, connecting wires.

Theory and formula

Let C be the constant current flowing through the potentiometer wire whose resistance per cm length is ρ. When key K_2 is open i. e., cell is not shunted, its e.m.f. E is balanced against length l_1 of the potentiometer wire, so that

$$E = Cl_1 \rho \qquad ...(1)$$

Next key K_2 is closed and a plug of R ohms taken out from the R. Box. It means the cell is shunted with resistance R and a

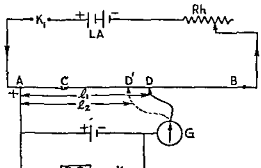


Fig 17.3

current i begins to flow through R and the cell. Consequently the p. d. between the electrodes of the cell falls from E to V. This p.d. = V, is balanced against length l_2 of the potentiometer wire.

So $V = C l_2 \rho$ ...(2)

Dividing $\frac{E}{V} = \frac{C l_1 \rho}{C l_2 \rho}$

i. e. $\frac{E}{V} = \frac{l_1}{l_2}$ ...(3)

Also $E = i(R+r)$

and $V = iR$

Dividing $\frac{E}{V} = \frac{R+r}{R}$

i. e. $\frac{E}{V} = 1 + \frac{r}{R}$

Substituting for $\frac{E}{V}$ from (3)

$$\frac{l_1}{l_2} = 1 + \frac{r}{R}$$

i. e., $\frac{r}{R} = \frac{l_1}{l_2} - 1$

or $\frac{r}{R} = \frac{l_1 - l_2}{l_2}$

i. e., $\boxed{r = R.\ \frac{l_1 - l_2}{l_2}}$

Knowing R, l_1 and l_2, the value of r can be calculated. l_1 is the balancing length when cell is not shunted with any resistance and l_2 is the balancing length when the cell is shunted with resistance R ohms from the resistance box.

Procedure

1. Make the connections as shown in the figure 17·3.

2. Close plug key K_1 so that the lead accumulator starts sending current through the potentiometer wire (keep K_2 open). Test the connections by pressing the jockey on the first wire and on the last wire. Deflections obtained in opposite directions in these two cases would mean the connections are correct. If deflection remains one sided, check the connections and if the connections are also correct, then increase current through the potentiometer wire by adjusting the rheostat so that galvanometer gives deflections in opposite directions on the first and on the last wire.

3. *After testing the connections as above, place the jockey* on the last wire, preferably near the other end B of the wire and adjust the position *of the slider on the rheostat so that galvano*-meter gives zero deflection. Measure the distance of the null point from the end A, *of the wire. This is l_1, corresponding to* e. m. f. E of the cell.

Note:—The above adjustment for having maximum value of l_1 is essential and preferable because then sufficient length of the wire will be available to us, for having different values

of l_2, to be obtained subsequently (l_2 is to be less than l_1 always provided constant current is passed through the wire.)

4. Next close plug key K_2 also, and take out a plug of resistance R ohms $= 5\Omega$ (say) from the resistance box, so that a current begins to flow through R and the cell and therefore p.d. between the electrodes falls from E to V. Balancing length l_2 corresponding to V is obtained and measured.

5. Knowing R, l_1 and l_2, value of r, the internal resistance of the cell can be determined using the formula

$$r = R\left(\frac{l_1 - l_2}{l_2}\right)$$

6. For obtaining different sets, shunt the cell with different resistances (R may be changed in steps of one or two ohms). Find balancing length l_2 everytime and thus calculate r separately for every set. Its value will be different for different sets.

Note:—Value of l_1 should be checked everytime when l_2 is measured, although l_1 is expected to be constant if rheostat is not disturbed.

Observations and Calculations

S. No.	Resistance in R. Box. R (ohms)	Balancing length when cell is NOT shunted with R. l_1 in cm	Balancing length when cell is shunted with R l_2 in cm	$l_1 - l_2$	$r = R.\frac{l_1 - l_2}{l_2}$
1.	Ohm	cm	cm	cm	Ohm
2.					
3.					
4.					
5.					
6.					

Mean value of r = ...ohms

But we see that value of r, the internal resistance of the cell

is NOT a constant quantity. *It increases with the current drawn from the cell.*

Additional Precautions

1. Basically the formula for internal resistance is $r = R\frac{E-V}{V}$.

Here E is constant, so for taking different sets V must be changed *by changing the value of R. In other words, different values of* l_2 should be obtained by shunting the cell with different resistances. Of course, l_2 could be changed by changing the current through potentiometer wire also but that would NOT be preferable, because that would not amount to changing the value of V.

2. *First balance the cell without shunting it and then balance* the same cell after shunting it with resistance R. If shunted cell is balanced first, then on balancing the cell on open *circuit, the* required balancing length may not possibly be available.

3. In no case, disturb the rheostat for one set of l_1 and l_2. It *would be advisable NOT to disturb it for other sets also* because in other sets, l_2 can be varied by using different values of R.

Oral Questions

1. What do you mean by the internal resistance of a cell ?

Ans—*It is the resistance offered by the electrolyte to the flow* of current inside the cell.

2. Upon what factors does the internal resistance depend ?

3. *What is the physical effect of internal resistance* of a cell ? Shuold the internal resistance of a cell be high or low ?

4. Why is the internal resistance of a lead accumulator so low as ·01 ohms, where as the internal resistance of a Leclanche cell is 4 to 5 ohms ?

5. Can this method *be used in case of a cell having a very* low internal resistance ?

6. Can or should l_1 be kept constant in all the observations ?

7. *What is the difference* between e. m. f. and potential

8. Will the internal resistance of a cell increase or decrease if—

(i) The distance between the electrodes is increased ?

(ii) More electrolyte is added ?

(iii) The electrods are raised vertically upwards so that their length dipping in the electrolyte decreases ?

(iv) More current is drawn from the cell ?

(v) The temperature of the electrolyte is increased ?

EXPERIMENT 17·4

Using potentiometer—

(I) Compare to given resistances.

(II) Determine a given low resistance.

Hint : Consult a book on theory or consult your teacher incharge and try to do the experiment, independently.

EXPERIMENT 17·5

Object—Compare the e. m. f's. of two cells by sum and difference method using potentiometer.

Hint—Let E_1 and E_2 be the e.m.fs. of the two given cells, E_1 being higher than E_2.

If the negative pole of the cell of e. m. f. E_1 is joined to the positive pole of the cell e. m. f. E_2, the e. m. f. of the combination is equal to their sum E_1 and E_2. Let the e.m.f. of this combination balanced against length l_1 of the potentiometer wire, through which constant current C is flowing.

Then $E_1+E_2=C\,l_1\,\rho$ ...(1)

If the negative pole of the cell of e. m. f. E_1 is joined to the negative pole of the cell of e.m.f. E_2, the e.m.f. of the combination is equal to their difference E_1-E_2. Let the e.m.f. of this combination be balanced against length l_2 of the wire.

Then $E_1-E_2=C\,l_2\,\rho$ ...(2)

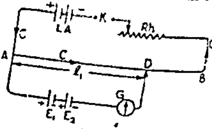
Dividing $\dfrac{E_1+E_2}{E_1-E_2}=\dfrac{l_1}{l_2}$

Apply componendo and dividendo

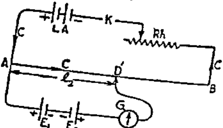
$$\frac{E_1+E_2+E_1-E_2}{E_1+E_2-E_1+E_2}=\frac{l_1+l_2}{l_1-l_2}$$

$$\text{i.e.}\ \frac{E_1}{E_2}=\frac{l_1+l_2}{l_1-l_2}$$

So knowing l_1 and l_2, the e.m.fs. of the two cells can be comp



SUM



DIFFERENCE

Fig. 17·4

***Note:**—In both the combinations, the positive pole of the c of higher e.m.f. (E) is to be connected at A i. where positive pole of the battery of the primar circuit is connected.*

18

ELECTROLYSIS AND VOLTAMETER

The process of decomposition of a liquid or a solution into ions, on passing electric current through it, is called electrolysis. The liquid or solution is called the electrolyte and the plates placed in the electrolyte are called electrodes. The plates connected to the positive and the negative pole of the battery are called the anode and the cathode respectively. The vessel containing the electrolyte and electrodes is known as voltameter.

(Note :—The difference between voltameter and voltmeter.)

As a matter of fact, the ions are already present in the solution itself. The passage of electric current simply helps the ions to move to opposite electrodes.

The voltameter can be used for the following purposes.

(1) Preparing gramophone records and printing blocks.

(2) Polishing metals.

(3) Comparing the equivalent weights.

(4) Determining Avogadro's Number.

A copper voltameter consists of a glass vessel containing $CuSO_4$ solution and three copper plates dipping into the solution. The two outer plates are placed parallel, a suitable distance apart and joined together by metallic strips to a common terminal. These are connected to the positive pole of the battery and hence constitute the anode. The cathode is constituted by the third copper plate placed parallel to and between the two outer plates, having its own binding terminal, which is connected to negative pole of the battery. (directly or indirectly through other apparatuses).

EXPERIMENT 18.1

Object—*Determine the electro chemical equivalent of copper using copper voltameter.*

Employ a tangent galvanometer as a current measuring instrument.

Apparatus—A copper voltameter, a lead accumulator, rheostat, a tangent galvanometer having coils of different turns, a plug key, a reversing key, a physical balance and a weight box containing fractional weights of superior quality. A large beaker containing water, an air blower, connecting wires, sand paper etc.

Theory and Formula :—

According to Faraday's first law of electrolysis, the mass of ions deposited on the cathode is

(i) directly proportional to the current c passed through the electrolyte,

(ii) the time t for which the current is passed.

So $m \propto c$

and $m \propto t$

i.e. $m \propto c\,t$

or $m = Z\,c\,t$, where Z, the constant of proportionality is known as the electro chemical equivalent of the metal used as anode.

$$Z = \frac{m}{ct} \qquad ...(1)$$

$c\,t = q$, the charge for which the unit is coulomb.

∴ Hence units of Z will be gms per coulomb.

The magnetic field F acting on the magnetic needle pivoted at the centre of a coil, due to current c amperes flowing in the coil is $F = \frac{2\pi nc}{10r}$

If the tangent galvanometer is set in the magnetic meridian and the magnetic needle makes $\angle\theta$ with the field H, due to earth, on passing current through it, then

$$F = H \tan \theta$$

$$\frac{2\pi\ n\ c}{10\ r} = H \tan \theta$$

i.e. $$c = \frac{10\ r\ H}{2\pi\ n} \tan \theta \qquad ...(2)$$

Substituting the value of c from equ (2) in equ (1).

$$\boxed{Z = \frac{m}{t} \cdot \frac{2\pi n}{10\ rH \tan \theta}} \qquad ...(3)$$

m = mass (in gms) of copper deposited on the cathode plate.

t = the (in secs) time for which the current is passed.

n = the number of turns of the coil in tangent galvanometer used.

r = radius (in cms) of the coil of the tangent galvanometer.

H = the horizontal component of Earth's field, at the place of experiment, (measured in Oersteds)

θ = the mean deflection of the magnetic needle pivoted at the centre of the tangent galvanometer coil.

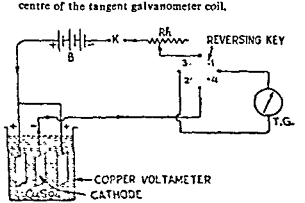


Fig. 18·1

Procedure

1. Make the connections as shown in the figure 18·1. See that you have connected the tangent galvanometer between the opposite terminals of the reversing key and NOT between the

neighbouring terminals. In case of these connections made ween the neighbouring terminals, the current through the tan galvanometer will NOT get reversed when subsequently i desired to do so. Between the other pair of opposite terminal the reversing key, an electrical circuit is developed through voltameter as shown in the figure 18·1.

2. See that the rheostat and the tangent galvanometer not placed close to each other, because in that case magnetic fi due to current flowing through the rheostat will affect the defl tion of the tangent galvanometer. There should be no magne substance placed near the tangent galvanometer. To keep t galvanometer and the rheostat far removed from each other, u long one piece connecting wire. Do not join two wires in air.

3. Remove the cathode plate from the voltameter and rub on both sides with sand paper to remove any spots present on Wash it with water, dry it and then weigh it in an accura balance, keep this weighed plate in reserve to be used subsequentl in the actual experiment. For testing the connections and adjus ing the current, a rough plate (dummy plate) is used as cathod i place of this weighed plate.

4. **Preparing the electrolyte**—Dissolve 30 gms of coppe sulphate crystals in 600 ccs of distilled water (mass = 600 gm). Sc specific gravity of the solution $= \frac{630}{600} = 1{\cdot}05$. Make the solution slightly acidic to make it conducting.

Calculate the area on both sides of the cathode plate dipping into the electrolyte. (NOT the total area but only the area inside the solution). To get a smooth and firm deposit, the current required is one ampere for 100 sq. cm area, of the cathode plate calculated above, provided the solution of specific gravity = 1·05, as prepared above is used.

5. **Setting the tangent galvanometer**—Make the compass box of the tangent galvanometer horizontal with the help of a spirit level. By looking from above with one eye closed, make the galvanometer coil parallel to the magnetic needle pivoted at the centre of the coil. Rotate the compass box to make the pointer read 0—0.

Next close key K and then insert opposite plugs 1 and 2 in the reversing key. Read both the ends of the pointer. Then take out plugs 1 and 2 and insert these in positions of 3 and 4 so that the current through the galvanometer coil gets reversed. Again read both the ends of the pointer. These readings should be the same as those recorded before reversing the current, and if the readings differ, they should differ slightly to 1° or 2°. If the difference is more, it means the coil has not been set properly in the magnetic meridian. So adjust its position and check that the diflection remains numerically the same before and after reversing the current. This is ONLY TEST of ensuring that the galvanometer coil has been set in the magnetic meridian.

6. Determining the radius of the coil—Pass a thread around the coil a number of times, say six times completely. Find its length and divide it by 6. This is the mean circumference $2\pi r$, from which r, can be calculated.

7. Choosing the proper number of turns of the coil and adjusting the current—Adjust the current with the help of rheostat so that with a 5 turn coil used, the deflection is in the vicinity of 45° (because for a deflection of 45°, the sensitivity is maximum.) Substituting these values of n and deflection θ, in the formula $C = 10\,\frac{r\,H\tan\theta}{2\pi n}$, roughly. Calculate the current C and see that it is approximately the same as desired in step 4.

Note:—A proper co-ordination of n and θ to have the desired value of C is essential. Sometimes when a large number of turns is used, resulting in a large deflection, the current C is so small that a detectable deposit is not obtained.

Sometimes when a small number of turns is used, then even for a small deflection, the current will be so large that the large deposit obtained will not be firm.

8. Testing the connections—Allow the current to flow for about five minutes with the dummy plate used as cathode. If after five minutes, on stopping current and taking out the plate, a deposit is observed on it, it means the connections are correct.

Note:--Sometimes, by mistake, the students connect the central plate to the positive pole of the battery and the outer plates to the negative pole. They discover to their surprise, at the end of the experiment, that no deposit has been obtained on the central plate, whose mass instead of having increased, has decreased. This is because deposit has been obtained on the outer plates due to the movement of ions from the central plate.

9. After setting the tangent galvanometer, adjusting the current and testing the connections, proceed with the actual experiment by replacing the dummy plate by the experimental plate weighed already. Start the current and the stop watch simultaneously. Read the ends of the pointer. If the deflection tends to change, keep it constant by adjusting the rheostat. Allow the current to flow for 15 minutes.

10. After 15 minutes, reverse the current through the tangent galvanometer. Pass the same constant current for another 15 minutes, noting the deflection again. After a total of 30 minutes, stop the current, remove the cathode plate, and immediately dip it into a beaker containing water. Move the plate to and fro in water so that any trace of $CuSO_4$ solution on the plate is removed. Dry the plate in the sun or by blowing on it hot air from an air blower. Weigh the plate again and thus find the mass of copper deposited on it.

11. The value of H for that place, where the experiment has been performed, can be cansulted from tables. Calculate Z using the formula (3) given above.

Observations

1. Mass of the cathode plate before passing current $= m_1$...gm
2. " " " " after deposition of copper $= m_2$...gm
3. Mean circumference of the coil, $2\pi r$ = ...cm
   radius of the coil r = ...cm
4. The value of H at the place (given) = ...oersteds
5. The number of turns of the coil used n = ...

For deflection of the tangent galvanometer

S. No.	Time for which current is passed	Direction of current through T. G.	Deflection at one end	Deflection at the other end
1	15 minutes	One direction	......	......
2	15 minutes	opposite direction	......	......

Mean deflection $\theta = \frac{\cdots}{4} = \ldots$

Total time for which current has been passed $= t = 30$ minutes
$= 1800$ seconds

Calculations

Mass of copper deposited $= m_2 - m_1 = m = \ldots\ldots\ldots$ gms

$$Z = \frac{m}{t} \cdot \frac{2\pi n}{10 rH \tan\theta}$$

$= \ldots\ldots\ldots\ldots\ldots\ldots$ gms/coulomb

Standard result of

$Z = \cdot000329$ gms per coulomb (For copher)

%age error =

Precautions

1. Before starting the experiment, check the setting of the tangent galvanometer by passing current through it in one direction and then in the opposite direction. The readings of the ends of the pointer should be the same numerically in both the cases and should not differ by more than 2°. In that case reset the galvanometer and recheck.

2. Read the ends of the pointer very carefully. Note that one division on the circular scale $= 1°$ and NOT $0{\cdot}1°$. Sometimes when the correct reading is 47° (say), the students wrongly read it as 53° or as 40.7°. Avoid such mistakes.

3. The actual experimental plate should be rubbed weighed accurately and placed separately. In its pla plate (dummy plate) is used for the purpose of setting th meter, adjusting the current and testing the connections.

4. The outer plates should be m de the anode by c their common terminal to the positive pole of the batt central plate should be connected to the negative pole connections should be tested by passing the current minutes. If a deposit occurs, on the cathod plate, it m connections are correct.

5. The number of turns of the coil used should be nei less nor too large. A 5-turns coil will best serve the purpo

6. The rheostat should be far removed from the g meter, otherwise on passing current, the rheostat will be solenoid and affect the deflection of the galvanometer if are placed near to each other.

7. Current should be kept constant throughout the ment with the help of rheostat.

8. At the end of the experiment, the cathode plat which deposit has been made, should be placed under ru water so that traces of $CuSO_4$ solution present on the pla removed.

9. The electrolyte should be made slightly acidic to ma conducting.

Oral Questions

1. What is a voltameter ? Is it different from voltmet
2. What is electrolysis ? State Faraday's law of elec lysis.
3. Define electro chemical equivalent. What is chemi equivalent ?
4. How current flows through the electrolyte ?

6. What precautions will you take to get a good deposit ? Why is it necessary to clean the cathode plate before starting the experiment ?

7. Could not the current be measured by an ammeter ? Why the tangent galvanometer is used ?

8. Why the current is reversed ? Does the current get reversed through the voltameter also.

9. Could A. C. be used in this experiment ? Give reasons for your answer.

10. Why two anode plates are used ? Couldn't the experiment be performod by using single anode and a single cathode ?

11. In the formula used, m is the mass of copper deposited on the cathode, and m is thus found out by determining the increase in the mass of the cathode. Could not m be determined by finding the decrease in mass of the anode.

Modifications

EXPERIMENT 18.2

Object—Using copper voltameter, determine the reduction factor of the five turn coil of a targent galvanometer. Verify the result by direct calculations. Given E. C. E. of copper = 0.000329 gms per coulomb.

Hint : The procedure of performing the experiment is exactly the same as that of the experiment 18·1.

$$Z = \frac{m}{ct}$$

and $C = 10\ K \tan\theta$

where K is the reduction factor of the T. G.

$$\text{So } Z = \frac{m}{10\ K \tan\theta . t}$$

$$\text{or } \boxed{K = \frac{m}{10\ Z \tan\theta \times t}} \qquad ...(1)$$

Knowing m, t and θ, value of K can be determined, Z being known to us.

By direct calculations,

$$K = \frac{rH}{2\pi n} \qquad ...(2)$$

Where r is the radius of the coil,

n is the number of turns of the coil used,

and H = the horizontal component of Earth's field at the place of experiment.

So knowing these quantities, K can be directly calculated from equation (2) and then its value compared with that determined from Equation (1).

Result

Experimental value of K determined from Equation (1) = ... amperes.

Value of K by direct calculations using Equation (2) = ... amperes.

Difference of the two values = ...

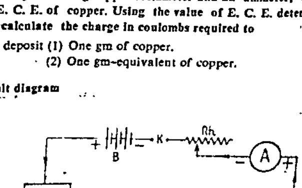
EXPERIMENT 18.3

Object—Using copper voltameter and an ammeter, determine the E. C. E. of copper. Using the value of E. C. E. determined by you calculate the charge in coulombs required to

deposit (1) One gm of copper.

(2) One gm-equivalent of copper.

Circuit diagram



Apparatus

A copper voltameter with an extra test plate of copper, a battery, key, a rheostat, an ammeter of range 1.5 ampere and with a small least count, a physical balance and a weight box, sand paper and connecting wires etc.

Theory and formula

$$m = Z\,c\,t$$

$$\text{or} \quad \boxed{Z = \frac{m}{ct}} \qquad \ldots(1)$$

Procedure

The experiment is performed on the same lines as described in experiment No. 18.1 the only difference is that instead of a tangent galvanometer, an ammeter is used for measuring the current and thus the current is directly known to us. Noting the time for which current is passed and finding the mass of copper deposited on the cathode, the value of Z can be calculated form equation. (1)

Suppose the value of Z determined by you is Z = 0.0003182 gms/coulomb. It means,

for depositing 0.0003182 gms of copper, charge required = 1 Coulomb

So „ „ 1 „ „ „ „ $= \frac{1}{\cdot 0003182}$ Coulomb

We know At. wt. of copper = 63·5

Valency of copper = 2

$$\text{So Equivalent weight} = \frac{\text{At. wt.}}{\text{Valency}}$$

$$= \frac{63.5}{2} = 31.75$$

So gm equivalent of copper = 31.75 gms of copper. Therefore for depositing one gm equivalent of copper i.e.

31.75 gms of copper, the charge required $= \frac{31.75}{\cdot 0003182}$ coulomb

= 99790 coulombs

19

MECHANICAL EQUIVALENT OF HEAT

According to first law of thermo dynamics, heat and work are inter convertible and work done is always proportional to the heat

i. e. $W \propto H$

or $W = J\,H$, where J, the constant of proportionality is called Mechanical Equivalent of heat.

$$J = \frac{W}{H} \qquad ...(1)$$

J and Joule's calorimeter have been named after Joule, the scientist.

EXPERIMENT 19·1

Object--Detremine the value of J, the mechanical equivalent of heat, using Joule's calorimeter.

Apparatus—Joule's calorimeter, a 6 volt battery, a rheostat a voltmeter of 6 volts range and an ammeter of 3 amperes range, a thermometer of least count $= \frac{1^\circ}{10}$ C, a physical balance and a weight box, stop watch, a plug key, connecting wires, sand paper etc.

Theory and formula

Work done by current—P. D. between two points is defined as the work done to carry unit charge from one point to another.

If p. d. between two points is V,

the work done to carry unit charge between those points $= V$

so " " " Q " " " $= QV$

so work done $W = Q\,V$

So $\qquad W = VCt$

Ohm's Law gives $\qquad V = CR$

So $\qquad W = CR.\ Ct = C^2Rt$

So $\quad$ if V, C and R are measured in e. m. u.

$$W = VCt = C^2Rt$$

if V, C and R are measured in practical units, i.e. in volts, amperes and ohms respectively

$$W = VCt \times 10^7 = C^2Rt \times 10^7 \text{ ergs} \qquad ...(2)$$

Heat produced $\qquad H = (M + ms)(\theta_2 - \theta_1) \qquad ...(3)$

Where $\;M$ = mass of water contained in the calorimeter.

m = mass of calorimeter.

s = specific heat of the material of the calorimeter.

θ_1 = the initial temperature.

θ_2 = the final temperature.

$$J = \frac{W}{H} = \frac{VCt \times 10^7}{(M + ms)(\theta_2 - \theta_1)} \text{ ergs/calorie} \qquad ...(4)$$

Procedure

1. Remove the ebonite knob of the stirrer and weigh the stirrer along with Joule's calorimeter, after properly cleaning the calorimeter. Note this mass m.

2. Pour water into the calorimeter, sufficient enough to immerse the heating coil in it. Filling half of the calorimeter would serve the purpose. Weight the calorimeter, and the stirrer along with the contents (water) and out of this mass, subtract m, the mass of calorimeter and stirrer. This will be M, the mass of water.

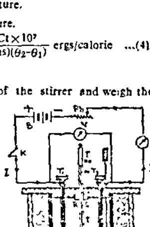


Fig. 19·1

3. Replace the lid of the calorimeter and pass the stirrer through one hole of the lid. Also replace the knob of the stirrer. Pass the thermometer through the piece of rubber which fits into the

central hole of the lid. By giving a screw type motion to the t mometre, adjust the height of the thermometer bulb so that bulb dips into water and at the same time it does not touch heating coil.

4. Make the connections as shown in the figure 19·1. will require a battery of three or four lead accumulators joine series. See that positive terminal of the voltmeter and of ammeter are connected directly or indirectly through other inst ments to the positive pole of the battery.

Note—*1. If positive terminal of the ammeter is joined to neg tive pole of the battery, the needle will be deflect towards the left beyond the zero division of the sca of the ammeter.*

2. Sometimes when the volmeter DOES give the readir but the ammeter reads zero, it usually indicates th the heating coil is broken and thus circuit is not bein completed so check the coil.

5. Close the plug key and adjust the rheostat so that vol meter reads between 4 to 6 volts. Do not apply more than 6 volt *because then electrolysis will set in and which is not desired.* S after setting the current in this way, open the plug key.

6. Stir water in the calorimeter and note its initial tempera ture θ_1. Start current in the circuit by closing the plug key and at the same time start the stop watch also.

7. Go on stirring the liquid with the stirrer and see that the current remains constant. If current tends to change, keep it constant by adjusting the rheostat.

8. When temperature has risen by about 5 or 6°C, stop the current and simultaneously note the time t (in seconds) for which the current has been passed. Record the highest temperature reached. *Let it be* θ_2' °C.

Applying the radiation correction

9. After the highest temperature has been reached, it will start falling. Go on stirring and note the fall in temperature a.e. in the same time t, for which the current had earlier been

Observations

1. Mass of the calorimeter and stirrer $m = ...$gms.
2. Mass of the calorimeter + stirrer + liquid (water) $= M_1 = ...$gms.
3. So mass of water $= M = M_1 - m = ...$gms.
4. Specific heat of the material of the calorimeter $s = ...$
5. Initial temperature of water $\theta_1 = ...^\circ C$
6. P. D. applied, i. e., voltmeter reading $V = ...$volts
7. Current passed, i. e., ammeter reading $c = ...$ amperes.
8. Time for which current is passed $= t = ...$minutes
9. Apparent final temperature $\theta'_2 = ...^\circ C$.
10. Fall in temperature of water recorded in the same time t is $\Delta\theta = ...^\circ C$.
11. Corrected final temperature $\theta_2 = \theta_2' + \frac{\Delta\theta}{2}$

$$J = \frac{Vct \times 10^7}{(M + ms)(\theta_2 - \theta_1)} \text{ ergs per calorie}$$

Result

$J = ...$ergs per calorie

Standard result $J = ...$ergs per calorie

% error =

Precautions

1. The thermometer should be so adjusted that its thermometer bulb remains immersed in the liquid and at the same time, it does not touch the heating coil.

2. Don't take much time in adjusting the initial potential difference and the current.

3. Don't set the potential difference to a value greater than 6 volts because as a higher potential difference electrolysis will set in. So the work done by current will not be wholly utilized in raising the temperature of the liquid.

4. Use a very sensitive thermometer, of least count equal to $\frac{1^\circ}{10}$C,

5. Throughout the experiment current in the circuit should be kept constant. If the current tends to change, keep it constant by adjusting the rheostat. Use lead accumulators of large ampere-hour capacities so that a constant supply of current is obtained for a long time.

6. Radiation correction must be applied to account for the loss of heat due to radiation. For this purpose, after the current is switched off, allow the liquid to cool, (while stirring it all the time) for the same time t, during which the current was passed. Note the fall in temperature. Then corrected rise in temperature =observed rise in temperature plus half of this fall in temperature

7. Stop the current as soon as the temperature rises by 5 or 6°C. A greater rise of temperature is not desirable because it will cause large radiation and for which the radiation correction explained in step 6 will not be applicable.

8. Sometimes when the heating coil is broken, the voltmeter DOES give deflection but the ammeter reads zero. In such a situation, check the heating coil and replace it or solder its snapped ends.

9. Current more than the rated capacity of the lead accumulator should not be drawn because large current drawn would produce large heat and so the lead plates in the accumulator will buckle and get spoiled.

Sources of error

1. The masses involved can not be determined very accurately.

2. The temperature throughout the mass of the liquid does not remain uniform.

3. Different parts of the apparatus possess different specific

precautions is only an approximation. It does NOT exactly account for the loss of heat due to radiation.

5. The thermometer also absorbs some heat and it is not taken into account.

6. The whole of the current as read by the ammeter does NOT pass through the heating coil. A part of it (through very small) passes through the voltmeter to cause deflection in it.

7. Some cooling is caused due to evaporation of the liquid from its surface.

8. The resistance of the heating coil changes when its temperature rises on passing current.

9. It is difficult to read exactly the temperatures which are not constant. A changing temperature involves some error in its measurement.

Oral Questions

1. State first law of thermo dynamics and derive Joule's mechanical equivalent of heat.

2. What are the important precautions to be observed in this experiment and what are the sources of error ?

3. What is radiation loss ? How is it reduced and how a correction is applied to account for the radiation loss ?

4. Is there any upper limit for the potential difference applied ?

Ans. Yes, about eight volts. A large p. d. applied will cause electrolysis and so the work done by current will not wholly get converted into heat.

5. Can you determine the specific heat of a liquid by this method.

Ans. Yes, if J is given to us.

6. What is the material of the heating coil used ?

Ans. In principle the wire should be of manganin so that its resistance remains constant with increase in temperature. However, since the ammeter and the voltmeter used are not sensitive, these

can't defect any such change in resistance. So a wire of nichrome is used, nichrome being cheap and possessing a high specific resistance also.

7. Is this an accurate method of determining J ? If not, why not ?

8. Enumerate other methods of determining J. Which one is the best and why ?

9. Name the liquid you will prefer to use in this experiment.

Modifications

EXPERIMENT 19.2

***Object*—Determine the water equivalent of Joules' calorimeter and determine your result by direct calculations also. Given $J = 4.18 \times 10^7$ ergs per calorie** (R. U. 1966, 1969).

Hint : $$J = \frac{W}{H}$$

or $$J = \frac{Vct \times 10^7}{(M + w)(\theta_2 - \theta_1)}$$

$$M + w = \frac{Vct \times 10^7}{J(\theta_2 - \theta_1)}$$

or $$w = \frac{Vct \times 10^7}{4.18 \times 10^7 (\theta_2 - \theta_1)} - M$$

$$w = \frac{Vct}{4.18\ (\theta_2 - \theta_1)} - M \qquad ...(1)$$

w, is the water equivalent of the calorimeter, and M is the mass of water contained in the calorimeter, t is the time in seconds for which the current is passed. The procedure is the same as in experiment No. 19.1.

By direct calculations

determined from equation (1) can come out to be negative also. Think why it can be so ?

EXPERIMENT 19·3

Object—With the help of Joule's calorimeter, find the specific heat of the given liquid. Given $J=4{\cdot}2\times10^7$ ergs per calorie.

(R. U. 1966, 69)

Hint : Use the given liquid in place of water and perform the experiment according to the details of experiment 19·1

Let M be the mass of the given liquid whose specific heat is S. Then

$$J=\frac{Vct\times10^7}{(MS+w)(\theta_2-\theta_1)}$$

$$MS+w=\frac{Vct\times10^7}{J(\theta_2-\theta_1)}$$

$$MS=\frac{Vct\times10^7}{4{\cdot}2\times10^7(\theta_2-\theta_1)}-w$$

$$S=\frac{Vct}{4{\cdot}2(\theta_2-\theta_1)M}-\frac{w}{M}$$

$$S=\frac{Vct}{4{\cdot}2(\theta_2-\theta_1)}-\frac{ms}{M}$$

where m is the mass of calorimeter and stirrer and s is the specific heat of the material of the calorimeter ($w=ms$)

Modification

EXPERIMENT 19·4

Object—Without using voltmeter, determine the resistance of the heating coil of Joule's calorimeter. Verify your result by Post Office Box. Given $J=4{\cdot}2\times10^7$ erg/calorie (R. U. 1966, 69)

$$J=\frac{W}{H}=\frac{Vct\times10^7}{(M+w)(\theta_2-\theta_1)}=\frac{c^2Rt\times10^7}{(M+w)(\theta_2-\theta_1)}$$

$$\therefore \quad R=\frac{J(M+w)(\theta_2-\theta_1)}{c^2t\times10^7}$$

$$\text{i.e.} \quad R=\frac{4{\cdot}2(M+w)(\theta_2-\theta_1)}{c^2t}\text{ ohms}$$

Where the symbols have their usual meaning. For verification, connect the ends of heating coil through its thick metallic rods, and connecting wires, infinite, fourth arm of Post Office Box and find out the resistance as usual. Then compare the two values.

Modification

EXPERIMENT 19.5

Object – Determine J with Joule's calorimeter using copper voltameter.

Given E. C. E. of copper = 0·000329 gm/coulomb

Hint : $J=\frac{W}{H}=\frac{Vct\times10^7}{(M+w)(\theta_2-\theta_1)}$

mass of copper deposited $m=Zct$ or $ct=\frac{m}{Z}$

$$J=\frac{Vm}{Z(M+w)(\theta_2-\theta_1)}\times10^7 \text{ ergs/calorie}$$

Join copper voltameter and Joule's calorimeter in series so that the same current passes through both for the same time t, in which (1) m gms of copper is deposited on the cathode of voltameter and (2) M gms of water contained in Joule's calorimeter of water equivalent w, gets heated up from θ_1 to θ_2°C. Substituting all these values, J can be calculated.

APPENDIX

Some useful Physical constants

Table-I Properties of solids

Solid	Young's modulus of elasticity Y	Density d	Specific heat s	coefficient of Linear expansion L	Thermal conductivity k
	Dynes/sq. cm	gm./c.c.		per °C	cal. sec^{-1} cm^{-1} (deg. °C)$^{-1}$
Aluminium	$7{\cdot}0\times10^{11}$	2·7	0·212	22×10^{-6}	0·50
Copper	$(10{\cdot}5-13{\cdot}2)\times10^{11}$	8·89	0·093	17·0 „	0·1
Iron (cast)	$(10-13)\times10^{11}$	7·60	0·118	10·2 „	0·11
Iron (wrought)	$(19-21)\times10^{11}$	7·85	0·115	11·9 „	0·17
Steel	$(19{\cdot}5-20{\cdot}5)\times10^{11}$	7·7	0·119	11·0 „	0·11
Gold	$8{\cdot}2\times10^{11}$	19·3	0·03	14·0 „	0·70
Silver	$7{\cdot}8\times10^{11}$	10·5	0·056	19·2 „	0·970
Zinc	$(8-11)\times10^{11}$	7·1	0·093	28·0 „	0·265
Lead	$1{\cdot}6\times10^{11}$	11·34	0·031	29·1 „	0·081
Brass	$(9{\cdot}7-10{\cdot}2)\times10^{11}$	8·1	0·094	19·0 „	0·26
Glass (flint)	$6{\cdot}8\times10^{11}$	2·9	0·16	8·4 „	0·002
Constantan (Eureka)	$16{\cdot}3\times10^{11}$	8·88	0·98	16·0 „	0·06
Wax (Paraffin)	... ...	0·9	... ...	......	......
Cork	... ...	2·24	0·49	......	0·12

Table-II Properties of Liquids

uid	Density d at 0°C	Freezing Point at Normal pressure (B. P.)	Boiling point at normal pressure (B. P.)	Specific heat S	Latent heat at normal B. P.	Coefficient of volume expansion	Thermal conductivity K
	gm/c.c.	°C	°C		Cal. per. gm	per °C	Cal. sec⁻¹ cm⁻¹ (deg. C)⁻¹
ry	13·6	−38·8	357	0·033	68	$1{\cdot}82\times10^{-4}$	$1{\cdot}97\times10^{-4}$
rines	1·26	17	290	0·580	......	5·5 "	6·37 "
ntine	0·87	−10	159	0·42	70	9·4 "	3·25 "
ine oil	0·80	...	...	0·52	......	9·1 "	3·6 "
r	0·9998 / 1·00 at 4°C	0·0	100	1·00	536	2·0 "	1·4 "
ol (l,OH)	0·79	−115	78	0·58	205	11·8 "	4·2 "
nce	0·89 (at 15°C)	5·5	80	0·41	93	12·4 "	3·2 "

Table III-Refractive index μ and critical angle (For sodium light)

Material	Refractive Index μ	Critial Angle	Material.	Refractive Index μ	Critical Angle
Glass (Flint)	1·65–1·96	37°	Water	1·33	48° 30'
Glass(crown)	1·58–1·56	41°	Alcohol (C_2H_5OH	1·36	...
Ice	1·301	...	Benzene	1·50	...
Diamond	2·24	24°	ether	1·35	...
Glycerine	1·47	44° 39'	Chloroform	1·41	...
Turpentine	1·48	...	carbon-di-sulphide	1·63	...
Kerosine oil	1·44	44° 12'	Any gas	1	...

Table IV-Specific resistance and temperature coefficients

Material	Specific resistance (at 0°C)	Temperature coefficient
	Ohm cm	per °C
Aluminium	$2{\cdot}82\times10^{-6}$	·0039
Copper	1·71 ,,	·0040
Iron	8·8 ,,	·0062
Zinc	5·7 ,,	·0040
Lead	20·9 ,,	·0043
Platinum	11·0 ,,	·0037
German silver	16·4 ,,	·0023
Brass (Cu 70%, Zn 30%)	6·0 ,,	·0010
Manganin (Cu 84%, Ni 4% and Mn 12 %)	44·0 ,,	·00002
Constantan (Eureka) (Cu 60% Ni 40%)	49·2 ,,	·00001
Nichrome (Ni 75%, Fe 12% or 11% and Mn 2%)	113 ,,	·00017

Table-V Velocity of sound

Medium (Gaseous)	Velocity at 0°C	Medium (Liquid)	Velocity at 28°C	Medium (solid)	Velocity at 20°C
Oxygen	316 Metres/sec	Water	1447 Metres/sec	Aluminium	5100 Metres/sec
Hydrogen	1262 ,,	Turpentine	1326 ,,	Iron	5130 ,,
Nitrogen	338 ,,			Steel	4990 ,,
Carbon-di-oxide	259 ,,	Alcohol	1275 ,,	Copper	3560 ,,
				Brass	3400 ,,
Air	332 ,,	Mercury	1047 ,,	Glass	5000 ,,
Water vapour	401 ,,				

Table VI-Electro-motive-force (E. M. F.) of cells and their internal resistance

Cell	E. M. F.	Internal Resistance
Daniel cell	1·08 Volts	1 to 5 ohms
Leclanche cell	1·5 ,,	1 to 5 ,,
Weston Cadmium cell	1·0183 ,, (at 20°C)	very high (900 ohms)
Bichromate cell	2·0 ,,	very low
Lead accumulator	2·1 ,,	0·01 to 0·1 ohms
Edison cell (Ni-Fe cell)	1·4 ,,	0·01 to 0·1 ohms

VII Electro chemical equivalents (E. C. E.)

Gold	·0006809 gms per coulomb	
Silver	·0011180	,,
Copper	·0003295	,,
Nickel	·0003043	,,
Lead	·0010731	,,
Zinc	·0003388	,,
Hydrogen	·00001045	,,
Oxygen	[illegible]	,,

... Mechanical equivalent of heat

IX Some useful formulae

$$\pi = \frac{\text{circumference of a circle}}{\text{Diameter of the circle } (2r)}$$

Circumference of a circle $= 2\pi r$

Area of a circle $= \pi r^2$ (r = radius)

Surface area of a sphere $= 4\pi r^2$ (r = radius)

Area of the curved surface of a cylinder of length l and radius r

$= 2\pi rl$

Volume of a sphere $= \frac{4}{3}\pi r^3$

Volume of a cylinder $= \pi r^2 l$

X Conversion Table

F. P. S.	C. G. S.	F. P. S.	C. G. S.
1 Inch =	2·54 cm	1 Pound =	453·6 gm
1 Foot =	30·48 cm	1 Ounce =	28·35 gm
1 sq. Inch =	6·451 sq. cm.	1 Poundal =	13825 dynes
1 sq. foot =	0·0929 sq. metre	1 Foot poundal =	$1{\cdot}356 \times 10^7$ ergs
1 cubic Inch =	16·39 c. c.	1 Horse power	= 1·356 Joules
1 cubic foot =	28·32 Litre	(550 foot pound per second)	= 746 watts

LOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170						5	9	13	17	21	26	30	34	38
						0212	0253	0294	0334	0374	4	8	12	16	20	24	28	32	36
11	0414	0453	0492	0531	0569						4	8	12	16	20	23	27	31	35
						0607	0645	0682	0719	0755	4	7	11	15	18	22	26	29	33
12	0792	0828	0864	0899	0934						3	7	11	14	18	21	25	28	32
						0969	1004	1038	1072	1106	3	7	10	14	17	20	24	27	31
13	1139	1173	1206	1239	1271						3	6	10	13	16	19	23	26	29
						1303	1335	1367	1399	1430	3	7	10	13	16	19	22	25	29
14	1461	1492	1523	1553	1584						3	6	9	12	15	19	22	25	28
						1614	1644	1673	1703	1732	3	6	9	12	14	17	20	23	26
15	1761	1790	1818	1847	1875						3	6	9	11	14	17	20	23	26
						1903	1931	1959	1987	2014	3	6	8	11	14	17	19	22	25
16	2041	2068	2095	2122	2148						3	6	8	11	14	16	19	22	24
						2175	2201	2227	2253	2279	3	5	8	10	13	16	18	21	23
17	2304	2330	2355	2380	2405						3	5	8	10	13	15	18	20	23
						2430	2455	2480	2504	2529	3	5	8	10	12	15	17	20	22
18	2553	2577	2601	2625	2648						2	5	7	9	12	14	17	19	21
						2672	2695	2718	2742	2765	2	4	7	9	11	14	16	18	21
19	2788	2810	2833	2856	2878						2	4	7	9	11	13	16	18	20
						2900	2923	2945	2967	2989	2	4	6	8	11	13	15	17	19
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8

LOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
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Name:

Vrijendra Biha

M.Sc. (prev.) chem.

organic practical

Govt colle.